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TRANSACTIONS

Of the Boston Society of Civil Engineers, the Engineers' Club of St Louis, the Western Society of Engineers, the Civil Engineers' Club of Cleveland, the Engineers' Club of Minnesota, the Civil Engineers' Society of St. Paul, the Engineers' Club of Kansas City, and the Montana Society of Civil Engineers.

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No. 5. I am doubtful about the metric system. The chief advantage I see is uniformity. The theoretic beauty of the metric base disappears because it never can be strictly true. The educational saving is a disadvantage if children are to grow up ignorant of vulgar fractions.

Some other disadvantages, briefly, are: 1. The meter and yard are unhandy measures for engineer's use. The foot is a "survival of the fittest." The unit of a system should be small enough to favor whole numbers rather than fractions. 2. The great expense, mechanically, of a change. 3. The decimal system lacks the $\frac{1}{4}$, $\frac{1}{8}$ and $\frac{1}{16}$. Therefore, I still use inches and eighths, although the decimals of a foot are quite at my tongue's end. I should be willing to make great personal sacrifices to secure an octonal or similar system of numerals.

I do not feel the present system of measures oppressive, or chafe under it in my business, which is that of a railroad and sewerage engineer.

What I desire on this question is more evidence from unprejudiced business men of foreign countries who have *actually been through the change.*

No. 6. (From a Member in hydraulic practice with a corporation.) * * * At this office are several members of the Society. Much of their time is given to computations and calculations which embrace decimal and common fractions and metrical measures. Habit renders the transposition from one system to the other an easy matter, and there seems to be no immediate call for the proposed change.

If the change is made, the assistants here would very quickly become familiar with the new methods, and the work would go on as now, with a probability that the labor would not be much, if any, less fatiguing than under the present system.

I am inclined to advocate moving slowly in the way of arbitrary legislation, believing that it is better to stick to the present system until a more decided demand exists in the fraternity for the proposed change.

No. 7. (From a Member connected with an educational institution.) As to the desirability of pressing the adoption of the metric system in this country I am in doubt. In my own limited experience I have not had the advantage of such a change brought to my mind strongly enough to bring about a positive opinion in its favor ; so that while I can see some probable benefits to arise from the introduction of the metric system in the United States, those advantages are with me at present theoretical only, and not yet convincing.

I am strongly of opinion that our own system of weights and measures could with advantage be simplified and a less number of units employed than now, and that any changes adopted should be in the direction of a decimal scale. I do not think the standard units employed in the metric system are so convenient in absolute size, or so well suited to the conditions of the ordinary transactions of life, as some of the units now in use among us.

I think the metric system can doubtless be employed with advantage among certain classes of scientific men, who have more direct concern with the weights and measures of other nations than do the mass of the people. But I do not as yet feel that it should be forced upon the country in any way. I rather entertain the belief that if it has such great ad-

vantages as have been claimed, it will win its own case, and will come into general use through concerted private action. When that movement shall have gone far enough, the passage of laws may be desirable to make the adoption of the system unanimous.

No. 8. My replies (affirmative) to these questions are not based upon the results of any special study, for I have made no study at all of the subject; but upon the general principle that as measurements are universal and must be exchanged and transferred from one end of the world to the other, it will be worth considerable trouble and expense to secure uniformity in methods and standards throughout the world.

No. 9. I favor the ultimate exclusive adoption of the metric system; although I do not feel disposed to grant that it is better than the foot (decimally divided of course) for the purposes of engineering and surveying. My objections to the metric system may be summed up by saying that the meter seems to my mind an exceedingly ill chosen unit in point of size. * * * Considering, however, the fact of its adoption by so many European nations and by scientific men in general, I am strongly in favor of the United States compelling by law its use after a certain date.

No. 10. I have long considered the system of weights and meaures in use in this country an antiquated absurdity, and have hoped to see a simple and consistent decimal system adopted in its place. * * * The fact that the meter has become the standard of so many nations, makes the adoption of any other by the United States a half-way measure, that would leave us only half as well off as we ought to be if we propose to make any change at all. I should be glad to see the metric system, in its entirety, in general use in this country; and its adoption by the government in its several departments would prove a strong entering wedge.

No. 11. The National Electric Light Association, after a careful and exhaustive investigation of the subject of wire gauges by a very competent committee, voted to have standards of the new gauge recommended by that committee prepared and distributed; viz.: a gauge specifying the diameters of sizes in thousandths (?) of a millimeter; *i. e.*, virtually the adoption of a decimal gauge in the metric system. The Edison Electric Light Company adopted for their systems a gauge based on thousandths of an inch of diameter; but are the only ones I know of who use this exclusively.

No. 12. * * * Some idea of the magnitude of the saving effected by the adoption of the metric system may be obtained from the following considerations:

An estimate, worthy of confidence, of the saving in the teaching of arithmetic in schools was published in the Proceedings of the American Metrological Society, Vol. 2, p. 193, in these words: "A schoolmaster who has had experience both in New England and in the West, and has taught the metric system, has made a careful detailed estimate; he puts the length of the arithmetical course at 162 weeks, and thinks it could be reduced to 88 weeks by substituting the metric system for our old weights and measures. The saving of 74 weeks, or 46 per cent. of the course of study in arithmetic, pursued simultaneously with other branches, would probably amount to nearly a half-year solid of school

life." Assuming the whole length of school life even at so extravagant a figure as ten years, the saving for more useful purposes would thus be five per cent. of the child's education, which is an important item. According to the report of the United States Commissioner of Education for 1884–5, the expenditures for public schools in all the States and Territories of the Union in that year amounted to upwards of $110,000,000, of which nearly $66,000,000 was paid for the salaries of teachers. A saving of 5 per cent. per annum on $110,000,000 is $5,500,000. Capitalized even at the excessive rate of 10 per cent., this gives $55,000,000 as the amount which it would on this basis appear that the United States could afford to pay out now, if it could by so doing get rid immediately of the perpetual annual expense hereafter of teaching ancient weights and measures in public schools. Private schools would have to be added to this to get a complete estimate even of school instruction. The number of children enrolled in the public schools was upwards of 11,000,000; hence, $5 for each child is the rate of the above $55,000,000 estimate; the number of "teachers and scientific persons" in the United States, according to the census of 1880, was nearly 228,000, while upwards of 17,000,000 of other persons were classed as having occupations. How much would the introduction of the metric system save these other 17,000,000 citizens? Evidently the waste of effort by the use of bad weights and measures after they were once familiar would be a less proportion than the waste of effort to learn them at first; but if, instead of 5 per cent. it were 1 per cent., or $\frac{1}{10}$ of 1 per cent., on the industry of the 17,000,000 persons having occupations in the United States, and 1 per cent., or $\frac{1}{6}$ of 1 per cent., on every citizen's income, it is a matter that we cannot afford to ignore.

That a valuable proportion of the labor that is expended upon business calculations could be saved by the substitution of the metric for the old weights and measures, cannot be doubted by any one who compares a few tables, such as have been in use for reference, with the corresponding ones appropriate to the metric system; although the contrast of calculations, if the tables were once made, and were known to be correct, and were always at hand when wanted, would obviously be less than that of the tables themselves. * * *

In science the United States as well as Great Britain has already changed to the metric system, and in business the change to the metric system is now going on; and the disproof of the allegation that it is impracticable is to be found conspicuously in such descriptions of the process as the following passages extracted from the discussion on British and metric measures which took place in the Institution of Civil Engineers, London, January, 1885 (Proceedings Inst. C. E., Vol. LXXX., Part II., reprinted in *Van Nostrand's Engineering Magazine*, September-November, 1885).

Mr. Percival Fowler said "he could speak from practical experience that in Spain, in a week, the workmen became thoroughly conversant with meters, centimeters, and millimeters, and he was certain that the difficulty of changing the English system of weights and measures to the decimal system had been greatly over-estimated."

Mr. Hamilton-Smythe said "In Austro-Hungary, for instance, the

metric system was extensively used by engineers for their own convenience for some years previous to its general introduction. It had become the interest of contractors and workmen to make themselves acquainted with the terms of measurement, in which the plans, specifications and bills of quantities supplied to them by their employers were expressed; and thus through the medium of the working class a knowledge of the system had been extensively spread through the mass of the people before the system was made legally compulsory for the purposes of general commerce."

"Mr. C. L. Hett remarked that in 1870 the Butterley Company obtained the contract for the Dordrecht Railway Bridge, and he had prepared the drawings for the steam cranes, scaffolding, etc., required in its erection. As the piling and superstructure of the staging had to be erected by a Continental contractor, the drawings were made to metric measures. Drawing scales were ordered with the most generally used English graduations on one edge, and corresponding metric divisions on the other. By the use of these scales all difficulty was overcome, and rapid progress made. The drawings of the bridge itself were prepared in Holland, under the supervision of the Dutch Government engineers, and were dimensioned in metric figures throughout. But in the works there was an outcry. The men at first said they could not, and would not work to such outlandish dimensions. The purchase of a few metric rules, however, settled the difficulty; and after a fortnight's practice one of the old hands who had been most opposed to them, admitted that the metric measures were much the easiest to use. * * * It should be mentioned that no member of the Butterley staff nor any of the workmen had had any previous experience of metric measures."

"Mr. F. Briffault pointed out two instances that had come under his notice in connection with two foreign water-works where the decimal and metric systems alone were used. The Brazilian Government had been supplied with 95,000 tons of pipes and connections from this country for the water-works of Rio de Janeiro, this quantity being divided between four manufactories. The castings were all weighed in kilograms, the weighing machines having been made expressly for the purpose. At first the men did not take kindly to the innovation; but at the end of a fortnight, after finding out the great saving of trouble thereby effected, they much preferred this system to the British. * * * In the case of the Constantinople water-works, similar satisfactory results had been obtained by the use of the decimal system; but in Turkey the advantage of it over the British system was even more marked. * * * The reduced lengths were measured in meters and centimeters, and the maximum weight allowed per lineal meter being fixed, the two had but to be multiplied together, and the result was metric tons and decimal parts of the same."

No. 13. Having had nearly a year's experience in the metric system as applied to linear distances on railroad work, I am heartily in favor of that system.

No. 14. I believe, from experience, in using other measures than those we now employ, that the adoption of the metric system would be attended with much less trouble and cost than is generally anticipated.

No. 15. (From a Member in active municipal practice.) I used the metric system of weights and measures exclusively for eight years while connected with the United States Coast Survey, and fully appreciate its advantages over the composite American system now in use. All my more important computations in my office are now made in the same system, as I think I save time in the end to reduce all my measures to meters before computing.

I believe the metric system the best for the reason that it is now, and has been for some years, the system in use by nearly all scientific writers. The meter itself must be considered an arbitrary standard. But I see no objection to that; the standard bar has been duplicated so many times it is impossible to lose it, and our old system is no better off. In practice I never felt that a long standard of 39 odd inches interfered at all with my work; and in fact for long distances it has many advantages over the short standard of 12 inches.

It seems to me that the question is one of decimal or binary divisions, and not on the value of the standard. That being the case, the decimal system now in part universally used has advantages over any new standard that can be devised. I use the old standard in my office for the sole reason that the new is not legalized, and I do not wish to make an innovation that may be changed by a new incumbent of the office. If the new system is made compulsory dating from a certain time, it will be a surprising matter how *quickly* every body will take hold of it. The trouble now in using it, lies not so much in ascertaining dimensions in meters, as in trying to express equivalents to feet and inches; or in thinking in one system and working in another. The use of the metric system, *as such*, and the handling of metric weights and measures, would quickly bring a knowledge of its value and simplicity.

I have dwelt only on the lineal measures because they apply directly to my work. I think, though, that the other measures have even better points than the lineal; mainly because every one is connected to the others in such a way as to make it possible to compare values without numerical reduction, which is impossible in our system.

PRESERVATION OF THE APRON AT THE FALLS OF ST. ANTHONY.

BY ARCHIBALD JOHNSON, MEMBER OF THE CIVIL ENGINEERS' SOCIETY OF ST PAUL.

[Read January 9, 1888.]

Before touching on the subject of this paper it may not be out of place to give a brief description of St. Anthony Falls and of the main works constructed for their preservation.

The bed of the river at Saint Anthony Falls is a stratum of magnesian limestone, overlying a soft sand rock of an unknown depth, and which wears away rapidly under a strong current of water. This stratum of limestone only extends about 1,200 feet above the crest of the falls. A section through it in the direction of the channel of the river, is nearly

triangular in shape. At the crest of the falls it is about 16 feet thick, and at the foot of Nicollet Island, it terminates in a thin layer.

The depth of the fall varies somewhat with the stage of water in the river, but it is never far from 43 feet. How far the falls extended

Fig. 1.

Falls of St. Anthony, Minnesota.

Scale: 1 inch = 450 feet.

NOTE.—Contours show original shape of spoil banks, as surveyed in 1882, and are referred to a stage of water 12 feet above the crest of the lower rolling dam.
a b c = Line of face of sand and lime rock in 1881.
d e c = Line of face of sand and lime rock in 1882.

down the river, I am not prepared to say. It is supposed by some that they extended as far as the confluence of the Mississippi with the Minnesota River, but there are unmistakable evidences that they

extended as far at least as the head of Meeker's Island. These evidences are the visible masses of limestone in the bed of the river which fell from the ledge.

The recession of the falls was caused by the sand rock wearing away, and thus undermining the limestone ledge and allowing it to break and fall in large masses until the destruction was arrested by improvements. In 1857 the Territorial Government of Minnesota granted a charter to two water power companies at Minneapolis, allowing them to construct dams and other improvements in the bed of the river. The result was that the river at the crest of the falls was contracted from a width of 1,250 feet to about 445 feet. After this was done the recession of the falls was very rapid, for from 1857 to 1868 they had receded in the narrow space not closed a distance of 300 feet. In addition to narrowing up the channel, a tunnel, known as the Eastman Tunnel, was excavated under the limestone ledge, commencing a short distance below the end of the ledge at the east channel and terminating near the foot of Nicollet Island. It was 6 feet square, and the roof was 6 feet below the limestone ledge. It was without lining of any kind. It was commenced in September, 1868, and completed in the fall of 1869, and was intended for a tail race from mills which were to be located on Nicollet Island. When the tunnel was completed, the water broke into it under the head of the limestone ledge, and it was not long before the water rushed through it in torrents. As the sand rock was soft it wore away rapidly, and the ledge was therefore left unsupported. Several breaks occurred in the ledge in the vicinity of the tunnel from 1869 to 1871, and various expedients were resorted to in checking the flow of water through it, but at first all attempts were failures. The recession of the falls was another source of anxiety, and in 1866 the water-power companies made an attempt to protect the falls by a timber apron, but the first high water destroyed it. A second attempt was made in 1869. In 1870 the citizens of Minneapolis, realizing that there was danger of the falls going out, invited J. B. Francis, the eminent hydraulic engineer, to examine the falls. He recommended a substantial apron of timber on the slope of the falls, with heavy cribwork at the bottom. He advised the uncovering of the tunnel for a distance of about 400 feet from the second break in the limestone ledge, and filling it with a puddle of clay and gravel. He also recommended the construction of long dams to keep the ledge constantly covered with water. Franklin Cook, a civil engineer of Minneapolis, had previously made this recommendation, and the object was to prevent the disintegration of the ledge by the action of the frost. In 1870 the aid of the general government was invoked to save the falls. Accordingly on July 11, 1870, Congress appropriated $50,000 for improving St. Anthony Falls. This was the first appropriation made by Congress. The plan adopted by the U. S. army engineers was essentially the same as recommended by Mr. J. B. Francis, but with the addition of a concrete dike under the ledge, extending from shore to shore. It is from 4 to 6 feet thick, and extends into the sand rock about 40 feet below the ledge. The object of it was to cut off all running water under the ledge, and the plan was successful. It was completed in 1876. The tunnel

above the dike was filled; the apron built by the citizens of Minneapolis on the slope of the falls, was extended and remodeled, and two rolling dams, each about 5 feet high, one at the crest of the falls and the other some distance above, were built to keep the ledge at all times flooded. The length of the lower rolling dam is about 445 feet, and it is over this space that all the water of the Mississippi passes, with the exception of what is used by the mills. The width at the toe of the apron, however, is only 355 feet. The apron consists of two planes, the principal one passing through the crest of the lower rolling dam, and is about 243 feet long with a slope of 5 horizontal to 1 vertical, and the other passing through the crest of the ledge along Farnham and Lovejoy's dam, and having a slope of about 2½ horizontal to 1 vertical. The portion of the apron forming this latter slope is termed the east wing, and it extends down about 100 feet below the toe of the main apron, and the line of its toe is nearly at right angles to that of the other. The apron is built of cribwork filled with stone, and is covered first with a course of 8-inch timber, and that with a course of 4-inch plank. The intersection of the two planes is termed the angle of the apron, and a space about 100 feet square between the east wing and main apron is also termed the angle.

After the main apron was completed in 1878, it was evident that the toe should in some way be protected from the scouring action of the water, and riprapping was naturally resorted to. In remodeling the apron on the west side, 5,700 cubic yards of limestone were excavated and used in protecting the toe of the apron. In addition to this, 2,300 cubic yards of granite boulders were dumped in at the east end of the apron to fill up a large hole there, and to riprap the crib-work at the toe. When this riprapping was completed it was believed that the apron was secure, the riprapping then reaching nearly to the surface of the water. Before this riprapping was done, there was a depth of 62 feet near the toe of the apron in the angle. In September, 1879, an examination was made at the toe of the apron in the angle, and it was found that there was a depth of 17 feet at the toe, and a depth of 30 feet a short distance out from the angle of the two planes of the apron. Shortly after this 250 cubic yards of limestone blocks weighing from 1,000 to 2,000 pounds were thrown in the angle. Another examination was made in September, 1880, when a depth of 29 feet was found at the toe of the apron in the angle, where in 1879 the depth, when first examined, was but 17 feet. About 60 feet from the angle of the apron and in the direction of the current a depth of 33 feet was found, where in 1879 the depth was 30 feet. In September, 1882, a depth of 34 feet was found at the toe of the apron in the angle, and 41.5 feet at a distance of about 40 feet from the toe of the main apron and that of the east wing. The corresponding depths in 1879 were respectively 17 and 30 feet. This gradual deepening shows that riprapping was a failure. All the riprapping along the toe of the apron had disappeared after the first floods. This is owing to the high velocity at flood stages, being not less than 50 feet per second, and aggravated at the angle by a powerful eddy that forms about 200 feet below the foot of the apron, and sweeps back along the east wing.

In September, 1882, flush boards were put on the crest of the lower roll-

ing dam for about two-thirds of its length from the east end, thus exposing about one-half of the apron. Soundings were taken along the main apron for a distance of 100 feet west from the east wing, and down stream about 180 feet. The cribwork of the toe of the main apron for a distance of 75 feet west from the angle and back for a width of 26 feet was entirely destroyed. As far west from this as the toe of the main apron could be examined the cribwork was without rock, and was afloat. The lower corner of the east wing had settled 13 feet from the undermining action of the eddy. The situation was certainly alarming, and the problem was what to substitute for riprapping to prevent the cribwork at the toe of the apron from being destroyed by the scouring and undermining action of the falls. Riprapping of boulders of such sizes as could be conveniently handled proved a failure, and there was no known precedent in engineering construction to answer the case. The idea was conceived to sink a covered crib of such dimensions and specific gravity as would not be disturbed by the action of floods. In the fall of 1882, a design of such a crib was accordingly made. The first work to be done, however, was to repair the space of 26 feet by 75 feet at the toe of the main apron in the angle, and afterward to level up a space in the angle to receive the covered crib. The apron was renewed in this space by sinking two cribs. The first was 26 feet wide, 67 feet long and from 28 to 32 feet deep in front, and 8 or 10 feet less depth in the rear. The other was 8 feet long in front, 20 feet wide and 26 feet deep. For a distance of two-thirds from the front of the cribs there was a flooring, so as to enable us to sink them, as they were built by loading them with rock. After they were sunk they were filled with rock and covered with 8 and 4 inch plank.

The framing of the crib to be sunk in the angle was commenced by a small crew about the 11th of December, 1882, but no material was put in place before the 1st of January. The construction of the crib was commenced on the ice in the recess or enlargement, and about ninety feet below where it was to be sunk. This was done so that the work of leveling the bed of the river in the angle could be carried on while the crib was being built. The bottom of the river was leveled by throwing rock at random in the deepest places, until the depth was reduced to 26 or 28 feet. After that the rock was lowered by means of grappling irons until the depth was reduced to 24 feet. A space 90 by 90 feet in the angle was leveled in this way. Before lowering rock with the grappling iron, a rope was stretched along the outer side of the area to be leveled and a sounding made at the end of the line. Whenever the sounding was 24½ feet or over, rock of suitable size was lowered to the foot of the sounding rod by means of a rope. The sounding rod, which was made of gas pipe, was passed through a ring on the grappling iron to guide it to the foot of the rod. When a distance of 90 feet had been gone over in this way, the rope was moved one foot parallel to its first position. Soundings were taken and rock lowered as before. The same process was repeated until the entire space was gone over. Soundings were then made over the entire area of 90 by 90 feet, and the depth in no place varied six inches from 24 feet.

The crib for the angle was built 80 feet square, with walls 6 feet

high. The depth of filling was 4 feet; and it was filled with rock and grouted with sand and hydraulic cement. It was constructed as follows:

The floor beams were constructed of 9 inch by 9 inch timbers, spliced together with a ship lap 2 feet long, and fastened by two ¾ inch screw bolts. Their ends are fastened to the lower timbers of the walls of the crib by 3 inch by 5 inch tenons. They are 4 feet apart, and every 8 feet

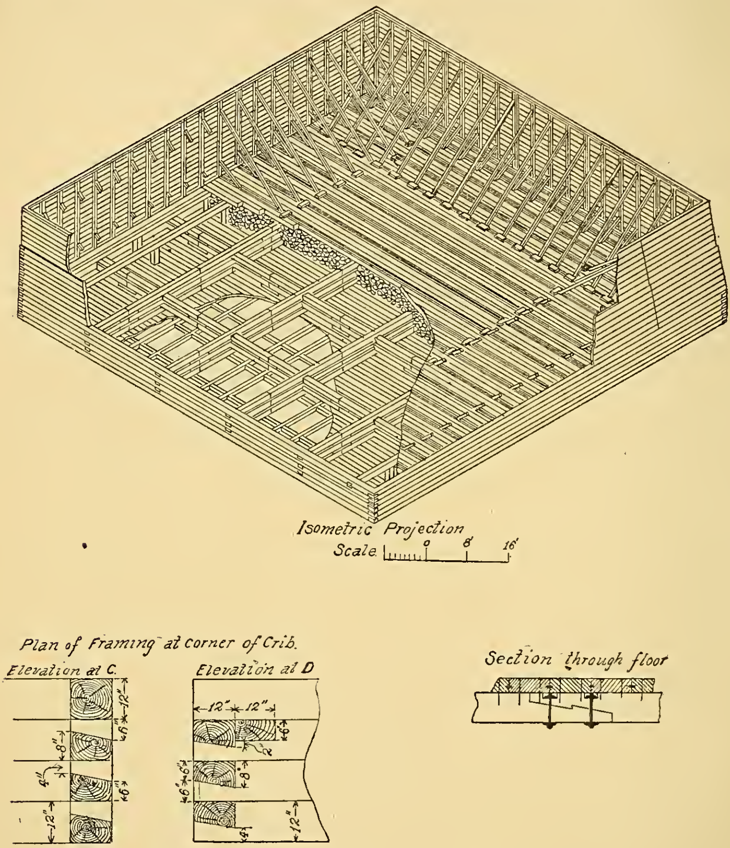


Fig. 2.

Crib Sunk March 6, 1883; in Angle at Foot of Apron.

Maj. C. J. Allen, U. S. A., *Chief Engineer.* Archibald Johnson, *Assistant Engineer.*

are struts of 9 inch by 9 inch timbers to stiffen them laterally, and are secured to the floor beams by 2 inch by 4½ inch tenons. Between the walls and first floor beams there are also struts. All tenons are pinned by oak tree-nails 1 inch in diameter. The flooring was sized down to 4 inches by 12 inches in a planer, and each side of the plank had a ¾ inch by ¾ inch grove in it. The top of the grove was 2 inches from the

top of the plank. As the planks were laid these groves were coated with white lead, and a tongue of seasoned pine, ¾ inch by 1½ inches, inserted into it. The planks were then spiked to the floor beams with two ⅜ inch by 8 inch boat spikes at each intersection, and two at the ends. Screw-bolts, 1½ inches by 6 feet 3½ inches, with a collar 16 inches from the lower end, to connect the covering with the floor beams, were put in 4 feet apart as the flooring was laid, with a rubber packing under the collar. The collar was hexagonal, so as to hold the rod from turning while the nut was being tightened under the floor beam. The rubber packing was to prevent water from coming up along the rod. All the joints of the floor were calked and pitched as fast as it was laid.

The outer walls were built of 12 inch by 12 inch square timber, and sized on two sides to an exact thickness of 12 inches. This sizing was done to insure close joints for calking. When wall timbers are adzed the workmen are apt to hollow out the timbers, and it is difficult to calk the joints. As the outer walls were being built the space inside was divided into squares of about 16 feet by cross walls of 12 inch by 12 inch timber resting on the flooring. The ends of these timbers forming these cross walls were dovetailed into the outer walls, and where they crossed one another each one was gained 1½ inches. The first two courses in the outer wall were fastened together by 1 inch screw bolts, 4 feet apart. The next four courses were fastened together by oak tree-nails 2 inches in diameter and 2 feet long, and 1 inch by 30 inch drift bolts of round iron. The joints in the walls were then calked and pitched. The crib was now towed to its position in the angle, and a curbing 16 feet high constructed on the outer walls to keep it afloat while it was being filled and covered, and to lower it gradually to the bottom after it was completed. The curbing was constructed by setting 6 inch by 6 inch by 16½ feet posts with 4 inch round tenons in the outer walls and tenoned into a 4 inch by 6 inch piece at the top. These posts were planked with 4 inch plank about half-way up, and the remaining distance with 2 inch plank. The first five courses of the 4 inch plank was then calked. The curbing was held in position by 1 inch rods passing through the 4 inch by 6 inch pieces at the top, with hooks at their lower ends hooking into eyebolts in the walls. The posts were braced with two sets of braces. The crib was then filled with rubble rock and grouted as previously stated. After it was filled it was covered with 12 inch by 12 inch timbers, every fourth one being screw-bolted to the floor beams by 1½ inch screw bolts 4 feet apart. The covering timbers were drift-bolted together laterally with 1 inch by 20 inch drift bolts 4 feet apart, and besides fastened to the cross walls by oak tree-nails 2 inches by 20 inches, so that when the covering was completed it formed one sheet connected with the bottom by these numerous screw-bolts. On the timbers through which the screw-bolts passed straps of iron ½ inch by 4 inches were placed to save the bolt heads from being injured by logs striking them. When the crib was completed it was lowered gradually by letting the water in through gates at the corners. It was sunk on the 6th of March, 1883. When it settled on the bottom no part of it varied more than six inches from a level, and the depth of water over it was 18 feet. After it was sunk the curbing was detached. After sinking it, 1,042 cubic

yards of limestone blocks, each measuring from 10 to 40 cubic feet, were placed around it to prevent its being undermined. From observations made at the time of sinking the crib, its specific gravity was 1.5, and its estimated weight was 1,674 tons. The riprapping around the crib may be removed by a strong current, but it is believed to be sufficiently strong and flexible to stand considerable undermining without being broken and destroyed. In the winter of 1885 and 1886 an examination was made to see if any changes had taken place since the crib was sunk, but it was found to be still level, with no disturbance of the rip-rapping around it. Up to this time, however, there had not been any floods in the Mississippi, and no material change could have been expected. The bottom has now scoured to such a depth at the foot of the apron that it is only heavy floods that cause much damage. About one-third of the water passing over the falls is concentrated in the angle, owing to the peculiar construction of the apron, and that which is subject to greatest scour is now protected; but until the damaged portion of the apron is repaired, and the space all along the foot of the main apron is protected by submerged cribs, similar to the one just described, the apron upon which the safety of the Falls of Saint Anthony now depends will be in constant danger during flood stages. Fig. 1 shows the apron at Saint Anthony Falls as now constructed. Fig. 2 shows a plan of the crib submerged in 1883.

ASSOCIATION OF ENGINEERING SOCIETIES.

PROCEEDINGS.

BOSTON SOCIETY OF CIVIL ENGINEERS.

JUNE 20, 1888 :—A regular meeting was held at the Society's rooms, Boston & Albany Railroad Station, at 7:30 P. M., President FitzGerald in the chair, fifty-four Members and twelve visitors present.

The record of last meeting was read and approved.

Messrs. Robert Forbes, Charles E. Houghton, Robert H. Richards and Henry B. Wood were elected Members of the Society.

The following were proposed for membership :

Mr. Louville Curtis, of Tyngsboro, Mass., recommended by H. C. Keith and C. W. Drake, and Mr. William M. Scanlan, of Boston, recommended by Edward Sawyer and D. W. Pratt.

The Secretary read a communication from the Engineers' Club of Kansas City, soliciting the co-operation of this Society in a movement to secure a proper inspection of bridges; also a communication from a Committee of the Western Society of Engineers upon the same subject. On motion of Mr. Stearns, both communications were referred to a special committee of three, to report at the September meeting. The chair appointed as that committee, Messrs. John E. Cheney, David H. Andrews, and Edward S. Shaw.

On motion of Mr. Keith, it was voted to omit the regular meetings of July and August.

Mr. Lucian A. Taylor read a paper entitled "A Brief Description of the Quincy Dam."

Mr. William S. Barbour, then read a description of the dam of the Cambridge Water-Works on Stony Brook, which was illustrated by about forty stereopticon views showing the work in its several stages.

Mr. John R. Freeman described a washout which occurred on the Canal at Nashua, N. H., and read a communication from Mr. Edwin F. Smith, Engineer of Canals, Schuylkill & Susquehanna Navigation Company, giving his experience in the construction of wooden dams.

Mr. Wilbur F. Learned gave an account of some of the difficulties encountered in the construction of the Chestnut Hill and the Parker Hill reservoir, and Mr. R. A. Hale described the Essex Company's dam at Lawrence, Mass.

A general discussion followed the reading of the several papers.

On motion of Mr. Stearns, the thanks of the Society were extended to Mr. E. F. Smith for his interesting communication.

[*Adjourned.*] S. E. TINKHAM, Secretary.

ENGINEERS' CLUB OF ST. LOUIS.

MAY 30, 1888 :—294th Meeting.—The Club met at Washington University at 8:15 P. M., President Holman in the chair ; twenty-eight Members and three visitors present. The minutes of the 293d meeting were read and approved. The Secretary read the following:

"The Committee appointed by the President to consider the advisability of this Club co-operating with the Kansas City and other engineering clubs in reference

to proposed State legislation for the safety of public bridges, as indicated in the herewith accompanying report of the Kansas City Club, do unanimously agree that we regard it desirable for our Club to co-operate with them for the object specified. We deem it the duty of the Club to aid such action from both a public and professional standpoint, and think that persistent effort will succeed in finally obtaining such legislative action on this important matter, in which the engineering clubs should take the initiative.

(Signed) " H. A. WHEELER, " C. H. SHARMAN, " MAX G. SCHINKE, } Committee."

On motion the report was received and the Committee discharged. Moved and seconded that the chair appoint a Committee of three to co-operate with Kansas City and other engineering clubs in furthering legislation on the subject of improvements in highway bridges ; carried. The Chair appointed as such committee Messrs. Robert Moore, C. H. Sharman and A. W. Hubbard. The Librarian notified the Club that Mr. Charles E. Jones had presented the library with eight bound volumes of the *Railroad Gazette*, from 1872 to 1879, formerly the property of the late Prof. C. A. Smith. On motion a vote of thanks was tendered Mr. Jones. Mr. R. E. McMath then read a paper on " The Water-Way between Lake Michigan and the Mississippi River, by way of the Illinois River." The author having been in charge of the government work on the Illinois River for some years, was able to treat the question in the light of experience. He referred to canals in general and gave special attention to the various schemes connected with the Illinois River, as well as the Hennepin Canal and the complications due to the Chicago drainage. He considered his subject under the following heads : Physical, Sanitary, Economical and Political. The author thought the scheme was of great importance and promised decided benefits. The paper was discussed by Messrs. Seddon, Professor Johnson, Wheeler, Bouton and Holman. On motion it was ordered that 1,000 copies of this paper be printed for circulation. The special order of the day was then taken up, being action on the recommendations contained in the report adopted at the last meeting, on the subject of National Public Works. The report provided for a committee on finance and one on correspondence. On balloting, the following committees were chosen : Finance, J. B. Johnson, R. E. McMath, Robt. Moore, W. B. Potter and E. D. Meier. Correspondence, J. B. Johnson, R. E. McMath, E. D. Meier, F. E. Nipher and C. M. Woodward. The meeting then adjourned. W. H. BRYAN, Secretary.

WESTERN SOCIETY OF ENGINEERS.

JUNE 6, 1888:—The 248th meeting was held, the President in the chair.

The minutes of the last meeting were read and approved.

Mr. Lewis B. Jackson, Chicago, Ill., was elected a Member.

Applications were filed from Robt. George Turknett, C. & N. W. Ry., Chicago, Ill., and George Eric Spaak, Wright Const. Co., Chicago, Ill.

The Secretary reported receipts since last meeting, $61.50 ; cash in hands of treasurer, $101.62; bills unpaid, $244.75. Bills for $51 were ordered paid.

The Secretary reported that after all dues were collected there would be a considerable deficiency at the end of the year. The Secretary was instructed to collect the additional dues of $2.50 per Member for the year 1888, or the full annual dues as established by the By-Laws as amended by vote canvassed March 6, 1888.

The President reported that the Trustees had not yet matured any recommendations as to the future policy of the Society, but that he expected to report upon

the matter at the next meeting. He also stated that the Committee on Highway Bridges had taken action in carrying out the instructions of the last meeting. Considerable discussion occurred in regard to the functions of State Engineers in the several States and upon the general question delegated to the Committee.

Upon motion of Mr. Liljencrantz, a Committee upon Employment was ordered to consider and report at the next meeting some plan and the necessary rules for carrying it into effect, for receiving and taking action upon applications for positions or for professional assistance from Members of the Society. After some discussion, Messrs. Liljencrantz and Parkhurst were appointed as a committee.

The Secretary read a letter from Mr. W. S. Pope, announcing the death of William L. Baker, of the Detroit Bridge and Iron Works, at his home in Detroit, on May 28. After remarks in regard to Mr. Baker, and also in regard to Charles Latimer, Messrs. Weston and Liljencrantz were appointed a committee to report suituable resolutions upon the lives of Mr. Latimer and Mr. Baker.

The Secretary read a paper by Alva M. Van Auken upon "Classification of Material in Railroad Construction," and a supplementary paper upon the "Commissary in Railway Field Parties." The paper was discussed at length by Messrs. Weston, Gottleib, Parkhurst, Liljencrantz and others. It was ordered that the paper be held until next meeting for further discussion, and that the remarks be put in writing for publication.

Upon motion the Treasurer was ordered to insure the library and property of the Society for $2,000 to January 1, 1890.

The next meeting was fixed for July 11.

[*Adjourned.*] L. E. COOLEY, Secretary.

CIVIL ENGINEERS' CLUB OF CLEVELAND.

JUNE 12, 1888 :—The Club was called to order by President Whitelaw at 8:45 P. M. Eleven members present.

Upon motion the reading of the minutes of the last meeting was dispensed with and the minutes as recorded by the secretary were approved.

The report of the Committee on Programme was read by Mr. H. C. Thompson, chairman.

After discussion of the work of the several committees for the year, it was decided that the semi-monthly meetings should be dispensed with, but that adjourned or special meetings could be held whenever necessary.

Mr. W. H. Searles exhibited some specimens of electric welding by the Thompson process, and gave a brief explanation of the process.

Mr. Whitelaw, in the name of Mrs. Simeon Sheldon, presented the Club with three works on engineering.

Upon motion of Mr. N. B. Wood, the thanks of the Club were tendered to Mrs. Sheldon.

The meeting was then adjourned till the second Tuesday in July.

JAMES RITCHIE, Secretary.

ENGINEERS' CLUB OF KANSAS CITY.

JUNE 4, 1888 :—A regular meeting was held in the Club-room at 7:45, Mr. T. F. Wynne in the chair. Those present were : Messrs. Jenkins, Stern, G. W. Pearsons, Waddell, Marsteller, Swain, Wynne, Breithaupt, F. L. Miller, Duncan, Potter, Kerr, Elmore, Allen, and nine visitors.

The minutes of the preceding regular meeting and the meeting of the Executive Committee were read and approved.

On canvass of ballots, the following were declared elected : As Members, Albert N. Connett, Bolton W. De Courcy ; as Associate Member, Victor M. Witmer.

The Secretary reported the following contributions to the library received during the past month: "Some Applications of Graphical Statics", Chicago Chapter American Institute of Architects, Jas. R. Willett; Official Railway List, 1888, Railway Purchasing Agent Company, Chicago; Transactions Engineers' Club of Philadelphia, December, 1887; Journal New England Water-Works Association, March, 1888; Report Illinois Society Engineers and Surveyors, January, 1888.

With reference to bridge reform, the Secretary presented, by title, letters from the American Society of Civil Engineers, Engineers' Club of St. Louis, Western Society of Engineers, Civil Engineers' Association of Kansas, Cincinnati Society of Engineers, Cleveland Engineers' Society, most of them expressing a desire to co-operate.

On motion of Mr. Waddell it was voted that a committee be appointed to arrange for an excursion of the Club sometime during the summer. The chair appointed Messrs. Breithaupt, Marsteller and Stern to act as such committee.

The Secretary read a letter of regret from Mr. Donnelly at being unable to read his paper that evening, but promised it at an adjourned meeting which it was decided to hold June 18th; also a letter from Prof. Fulton, saying that he should give up his rooms in the Deardorff Building July 1st, and asking the Club to meet in his new rooms in the Y. M. C. A. Building, if they desired. The matter was referred to the Executive Committee.

The paper of the evening, entitled "Crossing of the Chicago, Sante Fe & California Railway over the Missouri Pacific and Chicago & Alton tracks near Rock Creek Station," was then read by Mr. Breithaupt, and discussed by Messrs. Waddell, Pearsons, Goldmark, Wynne, Hoover and Stern. The bridge is a riveted pony truss, and was interesting on account of the necessity of keeping clear the several tracks over which it crossed on a skew. The discussion was chiefly with reference to the number and spacing of stringers for economy, and the effect of extreme rigidity in bridge superstructures.

Mr. Pearsons read a letter from Mr. John C. Trautwine, Jr., soliciting subscriptions in aid of the family of the late W. R. Kutter, of Berne. On motion of Mr. Waddell, Mr. Pearsons was chosen to collect such subscription and forward through Mr. Trautwine to Berne.

[*Adjourned.*] KENNETH ALLEN, Secretary.

JUNE 18, 1888 :—An adjourned meeting was held in the Club-room. Those present were Messrs. Knight, Donnelly, Wynne, Waddell, Kerr, F. Allen, Breithaupt, G. W. Pearsons, Witmer, Farnsworth, Potter, Marsteller, F. L. Miller, Mason, K. Allen and two visitors.

Minutes of the last regular meeting and of that of the Executive Committee were read and approved.

On motion of Mr. Wynne, it was voted that, if desired by the Club, the Members attending the Milwaukee Convention make known to the American Society of Civil Engineers its desire to have the next annual convention held in Kansas City.

Amendments by Mr. G. W. Pearsons were carried to the effect that the sense of our Club and of the business and railroad men of Kansas City be obtained by letter ballots and circulars, respectively.

A letter from Mr. C. L. Strobel, of the Western Society of Engineers, with reference to "Bridge Reform," was read asking the following questions :

1. Do you favor the appointment of a State Engineer ?

Do you consider it desirable for bridge engineers to adopt a scale of minimum rates for preparing working plans and specifications for bridges ?

3. Are you willing to co-operate with this Society by the appointment of a committee to consider and report on the subject of a scale of minimum rates?

On motion of Mr. Pearsons, it was voted to get answers to these questions from the Club by letter ballot, and on motion of Mr. Wynne, it was decided to express a willingness to co-operate in general in the matter, but that definite answers could not be given until reports from our Bridge Reform and Executive Committees were received.

The Secretary presented for Mr. Breithaupt a framed photograph of the bridge described in the paper read June 4. Also, the following were received for the library: Journal New England Water-Works Association, Proceedings Engineers' Society of Western Pennsylvania, Proceedings American Society of Mechanical Engineers for 1888, Proceedings Engineers' Club of Philadelphia, List of Members Boston Society of Civil Engineers, List of Members Kansas City Club.

The Secretary reported the following subscriptions to the Kutter fund:

Geo. H. Nettleton, $10; R. P. I., '79, $5; Matt Hoffett, E. A. Harper, B. R. Whitney, H. Carter, A. N. Stalnaker, E. Saxton, Captain Bourke, B. W. De Courcey, M. N. Wells, Kenneth Allen, J. F. Wallace, F. L. Miller, Wm. B. Knight, J. A. L. Waddell, J. H. Lasley, Alex. Potter, B. R. Whitney, Jr., B. L. Marsteller, John Donnelly, G. W. Pearsons, R. C. Pearsons, W. H. Breithaupt, $1 each—$22; total, $37.

Mr. John Donnelly read a paper on "Street Pavements of Kansas City," which was discussed by Messrs. Mason, Knight, Pearsons, Wynne, Farnsworth and others.

The following were proposed as Members: Edmund Saxton, by Wm. B. Knight and K. Allen; Walton Clark, by H. A. Keefer and K. Allen.

[*Adjourned.*] KENNETH ALLEN, Secretary.

as approximately indicating 50,000 and 100,000 cubic meters per hektar per annum respectively.

The purity of the effluent at Gennevilliers, whose clearness and brilliancy is strikingly noticeable as it issues from the drains, has been proved by numerous analyses. The amount of nitrogen, organic or ammoniacal, is extremely small, and does not amount to one milligram per liter (one part in one million). Microscopical examination of the effluent shows scarcely a dozen microbes per cubic centimeter; the water of the Vanne, containing 62; that of the Seine, at Bercy, 1,400; and the sewage 20,000 in the same volume.

Berlin.—The soil in the vicinity of Berlin is generally sandy, but is permeable only to a slight depth on account of an impervious stratum usually found at a depth of about 1.50 meters. The area prepared for irrigation is very extensive, as it has not been found practicable to apply large quantities of sewage per hektar. The area of the irrigation fields amounts to 31.8 square kilometers, divided into two groups, one of 17 sq. km. north of Berlin, and one of 14.8 sq. km. south of that city. The soil at the north irrigation fields is much heavier than at the south irrigation fields.

The effects of these different qualities of soil are shown by the averages in the following table, which gives some statistics of the irrigations during the year ending March 31, 1887.* It will be noticed that the amount of sewage distributed on the more permeable soil at a single watering is smaller, but that the total amount distributed per annum is greater, than on the heavy soil, the waterings being more frequent.

BERLIN SEWAGE IRRIGATION. 1886–87.

Locality of the sewage farm.	Amount of sewage distributed during the year	Area now prepared for irrigation	Average number of times the entire prepared area was irrigated during the year	The distribution was consequently equivalent to a single irrigation over the following areas	Average amount equivalent to a single irrigation annually per hektar	Average depth of sewage, equivalent to a single irrigation annually	Average rates of irrigation based on the actual area now prepared: Per hektar per annum	Average rates of irrigation based on the actual area now prepared: Average depth of sewage per annum
	cu. m.	hektars.		hektars.	cu. m.	cm	cu m	m.
Osdorf (south)	14,304,699	909.54	18.66	16,975.20	842.67	8.4	15,727.40	1.573
Gross beeren (south)	9,324,753	570.12	12.56	7,160.61	1,3[illegible]1.95	13.0	16,355.77	1.636
Falkenberg (north)	9,017,26	731.17	7.73	5,655.92	1,594.30	5.9	1[illegible],327.58	1.233
Malchow (north)	8,566,983	970.52	7.24	7,0[illegible]7.[illegible]7	1,[illegible]19.[illegible]	12.2	8,827.21	0.883
Totals and corresponding averages. South farms	23,629,452	1,479.66	16.31	24,135.91	979.01	9.8	15,969.50	1.597
Idem. North farms	17,584,244	1,701.99	7.45	1[illegible],683.09	1,386.43	13.9	10,331.58	1.033
Idem. General	41,213,696	3,181.65	11.57	36,819.00	1,119.35	11.2	12,953.55	1.295

* Bericht der Deputation für die Verwaltung der Kanalisationswerke. Berlin, 1887.

Monthly statistics of irrigations at the irrigation fields at Malchow were given in the report for 1884–85, from which the following table is compiled. It will be seen that the amount of sewage applied per hektar was tolerably uniform during the half year from June to November, inclusive, and that during the remaining half year the amount was reduced every alternate month. The large number of waterings each month is explained by the fact that the land prepared at Malchow for irrigation comprised 9.7 square kilometers. On this extensive area many local waterings can be made simultaneously. Including the overlappings of the local waterings, the entire prepared area was irrigated, on the average, 7.5 times during the year. The amount of sewage

MONTHLY STATISTICS OF IRRIGATION AT MALCHOW, 1884–85.

MONTH.	Amount of sewage distributed	Number of waterings.	Total area of waterings.	Average area of one watering.	Average amount of one watering per hektar.	Average depth of one watering.
	cu. meters.		hektars.	hektars.	cu meters	cm.
April	480,000	191	445.48	2.3324	1,077	10.8
May	582,000	263	615.07	2.3387	946	9.5
June	606,000	225	525.90	2.3373	1,152	11.5
July	645,000	240	558.89	2.3287	1,154	11.5
August	642,000	230	535.83	2.3297	1,198	12.0
S ptember	645,000	230	536.14	2.3310	1,203	12.0
October	675,000	228	521.75	2.2884	1,294	12.9
November	582,000	236	566.97	2.4024	1,027	10.3
December	586,000	263	651.74	2.4781	899	9.0
January	558,000	238	552.83	2.3228	1.009	10.1
February	543,000	261	608.98	2.3333	892	8.9
March	583,000	239	557.56	2.3329	1,046	10.5
Totals and averages	7,127,000	2,844	6,677.14	2.3478	1,067	10.7

distributed daily averaged 19,500 cubic meters. The average amount put on each hektar of total irrigated area was 1,067 cubic meters and the average amount put on each of the 970.27 hektars of prepared area, during the year, was 7,348 cubic meters, or a total depth of 0.735 meters. The average amount of sewage put on these irrigation fields in 1886–7 was 8,827 cubic meters per hektar, or a depth of 0.883 meters.

Nearly the entire extent of the irrigation fields is underdrained with ordinary tiles. They are usually laid from 1 meter to 1.25 meters below the surface. A less depth is not considered advisable, as the danger of stoppages from fine sand and silt would be imminent, and as the purification of the effluent would be less satisfactory were the stratum of earth shallow. But this depth cannot always be attained on account of the higher position of the bottom of the effluent ditches. Of the 3181.65 hektars prepared for irrigation, 3052.40 hektars are already drained.

The annual rainfall at Berlin ranges from 45 cm. to 63 cm.; the average being 54 cm. The mean temperature is + 0.82° C. in December,

— 1.12° in January and — 0.50° in February. In February, 1865, on account of a deficient covering of snow, the frost penetrated the earth to a depth of 75 cm. Observations of the temperatures of the earth have been taken at fourteen different points and at 3 different depths, 0.50 meter, 1 meter and 3 meters. The average of these observations on the 1st and 15th of each month are given for the years 1882 to 1885 inclusive, and show that the frost did not penetrate to a depth of 50 cm. during that period; the lowest temperature reported at the depth of 50 cm. being 2.16° C. in February, 1885. The following table gives the average temperatures of the earth during 1884 and 1885 for the whole territory observed and for the 1st and 15th of each month.

AVERAGE TEMPERATURES OF THE EARTH IN 1884 AND 1885.

Date.	1884. Depths of			1885. Depths of		
	0.5 meter.	1 meter.	3 meters.	0.5 meter.	1 meter.	3 meters.
	C°.	C°.	C°.	C°.	C°.	C°.
Jan. 1....	4.50	6.30	9.73	4.76	6.33	9.94
" 15.....	4.50	5.77	8.93	3.92	5.52	9.42
Feb. 1 ...	6.07	6 33	8.60	2.16	4 15	8.72
" 15 ...	6.27	7.03	8.72	3.31	4.80	8 41
March 1...	5.06	6.35	8.66	5.07	5.72	8.16
" 15 ..	6 23	6 11	8.20	4.79	5.70	8.16
April 1....	7.26	7.37	8.73	6.36	6.52	8.17
" 15 ..	8 23	8.30	8.74	7 39	7.72	8.45
May 1.....	8.21	7.90	8.83	12.63	11.09	8 95
" 15.....	13.44	10.94	9 46	10.15	10.32	9.72
June 1 ..	13.71	12.58	10.85	14.34	12.53	10.21
" 15	14.63	13.30	11.20	16 21	14.43	10 98
July 1	15.54	14 16	11.68	18 14	16.01	11.97
" 15	18.89	16.84	12.43	19.19	17.19	12.76
Aug. 1 ...	16.58	16.14	13 30	17.08	16.37	13.46
" 15. ..	18.30	16 95	13.57	17.19	16.56	13.65
Sept. 1....	16.31	16.22	14.12	14.42	14.59	13.63
" 15....	16.58	15.89	14.07	14.36	14.36	13.53
Oct. 1....	15.55	15.38	14.03	13.11	13 99	13.59
" 15 .	11 70	13 37	13.82	11.69	12.42	13.23
Nov. 1....	9.30	10.98	13.08	8.92	10.51	12.51
" 15. ..	8.18	9 99	12.38	7.25	8.97	11 87
Dec. 1.....	4.14	6.65	11.34	6.16	7.12	11.06
" 15. ..	7.13	7.43	10.46	3.76	6 01	10.37

The amplitudes of the oscillations in temperature are essentially similar at the depths of 0.5 and 1 meter, but at the depth of 3 meters the amplitude is much reduced by the protection afforded by the earth. The winter of 1884 was the mildest of the four reported.

The reports of the Berlin deputation contain detailed analyses of the effluents and descriptions of the appearance and color of the samples. Some specimens were clear and colorless, others were slightly yellowish or turbid, with a few flocculent particles and a slight odor. The analyses given in the following table are from the reports for 1885-86 and 1886-87. The samples selected from those reported, give the greatest and least amounts of total ammonia, and, where practicable, give analyses in cold weather and in hot weather of effluents from each type of irrigation practiced at Berlin.

ANALYSES OF EFFLUENTS FROM THE SEWAGE FARM AT OSDORF.
(Parts per 100,000)

	From the beds.				From the meadows.			
	May 1, 1885.	July 31, 1885.	Aug. 1, 1886.	Feb. 28, 1887.	Sept. 30. 1885.	Nov. 14. 1885.	Aug. 30. 1886.	Nov. 1, 1886.
Dry residue	82.24	64.40	83.68	88.24	84.72	75.28	89.60	91.92
Loss on ignition of the same	17.12	7.84	11.28	11.52	8.08	11.76	11.92	12.80
Residue after ignition	65.12	56.56	72.40	76.72	76.64	63.52	77.68	79.12
Potassium permanganate required	1.42	2.36	1.32	5.93	0.95	3.70	2.31	1.86
Ammonia	0.24	0.03	0.07	1.00	0.01	0.10	0.03	0.04
Organically combined ammonia	0.04	0.03	0.03	0.09	Traces	0.07	0.01	0.04
Nitrogen trioxide (N_2O_3)	0.86	0.27	0.32	1.24	0.00	0.23	0.00	0.00
Nitrogen pentoxide (N_2O_5)	19.42	7.29	6.67	1.76	11.57	10.73	12.66	10.26
Sulphur trioxide (SO_3)	......	......	......	......	4.02	......	......	......
Phosphorus pentoxide (P_2O_5)	Traces	Tr'ces	Traces	Traces	Traces	Traces	Traces	Traces
Chlorine (Cl)	10.92	12.07	13.29	17.48	13.78	13.71	16.38	10.01
Potassium oxide (K_2O)	......	......	......	......	1.58	......	......	......
Sodium oxide (Na_2O)	......	......	......	......	13.80	......	......	......

	From the basins.			
	Nov. 14, 1885.	Feb. 14, 1886.	June 30, 1886.	Jan. 31, 1887
Dry residue	57.92	108.96	88.04	120.96
Loss on ignition of the same	8.32	27.02	12.92	21.28
Residue after ignition	49.60	81.76	75.12	99.68
Potassium permanganate required	3.89	17.07 (?)	2.56	5.53
Ammonia	0.02	1.40	0.36	1.60
Organically combined ammonia	0.08	0.08	0.04	0.18
Nitrogen trioxide (N_2O_3)	0.29	1.27	0.57	1.54
Nitrogen pentoxide (N_2O_5)	2.38	0.00	11.15	11.42
Sulphur trioxide (SO_3)	......	......	......	......
Phosphorus pentoxide (P_2O_5)	Traces	Considerable	Strong traces	Traces
Chlorine (Cl)	13.29	20.75	14.20	20.64
Potassium oxide (K_2O)	......	......	......	......
Sodium oxide (Na_2O)	......	......	......	......

Leamington.—The published reports of English practice in sewage irrigation do not enter into detail nearly as much as do the French and German reports. This is to be regretted, as examples of sewage disposal are much more numerous in England than on the Continent. The following statistics of sewage irrigation at Leamington, Doncaster and Croydon are from the Report of the Judges appointed by the Royal Agricultural Society of England to adjudicate the prizes in the Sewage Farm Competition, 1879.* Two prizes, each of the value of one hundred pounds, were offered for the best-managed sewage farms in England and Wales. One prize was for the best managed sewage farm utilizing the sewage of not more than 20,000 people; the other was for the best managed sewage farm utilizing the sewage of more than 20,000 people.

The sewage farm at Leamington comprises 764 acres, 0 roods, 31 p. The population contributing sewage is 23,000, being 30 persons per acre of whole area of farm, or 142 persons per acre actually irrigated. It has

* *Journal of the Royal Agricultural Society of England,* 1880.

probably a larger area in proportion to population than any other sewage farm in England. The prize for sewage farms dealing with the sewage of more than 20,000 people was awarded to this farm.

"In the year 1878, 161 a. 0 r. 10 p. of land were irrigated with sewage; the average quantity of sewage applied in this year having been 5,553 tons per acre, or equivalent to an irrigation depth of 55 inches on every acre irrigated. The volume, however, given to different crops varies. In the case of rye-grass, as much as 11,912 tons per acre have been applied, which is equivalent to an irrigation depth of 117.8 inches: mangolds 8,265 tons per acre, which is equivalent to an irrigated depth of 81.83 inches; while upon land on which potatoes and savoys have been grown only 2,275 tons per acre have been applied, or an irrigated depth of 22½ inches. The soil of the farm varies in character. The greater portion, however, is very light land upon a gravel subsoil, but some portions are clay. * * * As far as possible all the solids of the sewage are pumped with the liquid. * * * The land is mostly drained, the stiff land at a depth of 4 feet, with the drains 40 feet apart, and the light land 5 feet deep, with the drains 60 feet apart. There was no surface effluent from the farm, and very little effluent from the land drains at the time of our inspections, compared with the volume of sewage which is applied to the land. * * * The prejudice which still exists in many parts of England against milk, rye-grass and vegetables grown by sewage have here all been overcome, if they ever existed, and in all seasons there are customers for all that is grown. * * * The farm was very clean, and in a good state of cultivation. * * * Twenty-six persons reside on the sewage farm, including fourteen children, and twenty others are employed who do not reside on it. At no time has there been any form of epidemic disease."

Doncaster.—The sewage farm at this place was awarded a second prize in the class of towns having a greater population than 20,000. "The farm contains an area of 304 a. 3 r. 11 p., of which 229 a. 1 r. 27 p. were irrigated in 1878, 75 a. 1 r. 24 p not being irrigated. It was established in 1873, and receives the sewage of a population of 21,000 persons (being 69 persons per acre of whole area of farm, or 92 per acre actually irrigated). * * * At the sewage works there are fixed in the sewers cages which form screens to keep out the larger solid matters from the pumps, all the rest of the sewage being pumped on to the farm. * * * The soil is of a somewhat variable character. The larger portion of the farm is very light land, resting upon a subsoil of red sand, the remaining portion consisting of red stratified clay. * * * The light land is of an extremely porous character. * * * About 90 acres of the farm have been underdrained. In the porous soils, the drains are 6 feet deep; on the loamy soils, 4 feet 6 inches deep; and in the clay lands they are 4 feet deep. The drains vary in distance from 11 yards to 40 yards apart. Notwithstanding the large quantities of sewage which were poured upon the surface at all periods of our inspection, it was found that there was no surface effluent, and that the under drains also yielded little or no effluent water. * * * The quantity of sewage pumped on to the farm in 1878 was 921,440¼ tons [equivalent to 4,016 tons per acre irrigated]. The volume of sewage applied to

various crops differs enormously. As much as 17,505 tons per acre were applied in 1878 to rye-grass, which is equivalent to a vertical irrigation depth of 173 inches in the year. Mangolds received 6,455 tons, or 64 inches, in vertical depth, and permanent grass 4,504 tons per acre, or 44 inches in depth, while beans received only 188 tons per acre, or 1¾ inches in depth. * * * The sewage is applied to various crops in the spring and summer, and also to a few crops in the winter; but it is largely applied to fallow land in the winter time. * * * The land is well tilled, fairly cleaned and a large quantity of produce is raised from a naturally poor soil. * * * There has been no form of epidemic disease amongst the men or their families, and no deaths have occurred on the farm."

Croydon.—"At Croydon (Beddington), sewage irrigation as a mode of purifying sewage has been practiced for a longer period than in any other town in England. * * * At the present time the farm contains 445 a. 2 r. 23 p. Not more than 330 acres of the whole farm are at present under sewage irrigation at any time. Having regard to the fact that certain crops (such as oats) are not irrigated during their period of growth, the area of land to which the sewage is actually applied does not exceed 320 acres all the year round. The population of the district draining on to this farm is estimated at 55,000, so that the sewage of at least 170 persons is constantly applied to each acre of land irrigated in the course of a year. The quantity of sewage applied in twelve months, from October, 1878, to September, 1879, was equal to a daily volume of 140 (imperial) gallons per head per day of the population. * * * Previous to the liquid sewage passing on to the land, it is passed through Mr. Baldwin Latham's patent sewage extractors, which remove the sand, solid fæces, paper, etc. * * * In the twelve months from October, 1878, to the end of September, 1879, 12,557,790 tons of sewage were passed on to the farm from both outfall sewers, an amount equivalent to a depth of 388.5 inches on the 320 acres actually irrigated [39,243 tons per acre per annum], in addition to the local rainfall, which was 33.4 inches during the same period—the actual quantity of sewage applied per acre at Croydon being seven times greater than that applied at Leamington during the same period. * * * It is a light soil, resting on a gravel subsoil. The farm is admirably adapted for irrigation, both from the character of its soil and the gradient of its slopes. * * * The farm is not drained to any great extent, and it is more or less water-logged, and it would be greatly improved both by surface and subsoil drainage; but what is urgently required is the removal of the large and increasing volume of the subsoil water from the sewers. Notwithstanding the enormous volume of sewage which is poured on to this land, the effluent flowing off at all periods of our inspection was clear and limpid."

The amount of sewage here reported seems excessive when compared with other cases. The water-logged condition of the soil also indicates an excess of sewage. It is to be regretted that no analyses were given by the judges, to show the degree of purification attained.

Medfield, Mass.—The amount of sewage distributed at Medfield is estimated by Mr. Brooks at 4,250 cubic feet every 24 hours the year

round. As the area of the filter bed is one acre, this is also the yearly average per acre per day, and is equal to 108,543 cubic meters per hektar per annum. This result agrees very closely with the result of the Paris experiment on filtration without cultivation.

SUMMARY.

The preceding statistics, which by no means include all that might be mentioned, may serve to point out, in a general way, the amount of sewage which may be disposed of under conditions analogous to those obtaining in the several cases mentioned.

The following table gives a summary of the results, reduced to uniform measures:

STATISTICS OF SEWAGE IRRIGATION AND FILTRATION.

Locality.	Nature of the earth.	Remarks.	Date.	Volume of sewage. Per hektar per annum	Volume of sewage. Per acre per annum . .	Volume of sewage. Per acre per day (yearly average)	Average depth of sewage per annum.	
				Cu. meters.	Tons.	Cu. feet.	Meters	Feet.
Berlin. Malchow	Heavy.	Irrigation.	1884–85	7,348	2,925	288	0.735	2 41
" "	"	"	1886–7	8,827	3,514	346	0.883	2.90
Doncaster....	Sand or gravel.	"	1878	10,089	4,016	395	1.009	3.31
Berlin. Falkenberg...	Heavy.	"	1886–7	12,327	4,907	483	1.233	4.04
Leamington.	Mostly gravel.	"	1878	13,949	5,553	546	1.395	4.58
Berlin. Osdorf.	Sandy.	"	1886–7	15,727	6,261	616	1.573	5.16
Berlin. Grossbeeren..	"	"	1886–7	16,355	6,511	640	1.636	5 37
Paris. Gennevilliers..	Sand and gravel.	Market gardening (working average).	1875–83	33,300	13,270	1,305	3.330	10.94
" "	do.	Filtration and cultivation.	1883	48,940	19,483	1.916	4.894	16.06
" "	do.	From experiments	Early	50,000	19,905	1.958	5.000	16 40
" "	do.	Filtration without cultivation.	1881–82	92,348	36,763	3,616	9 235	30.30
Croydon. Beddington	Gravel.	Broad irrigation.	1878–9	98,578	39,243*	3 860	9 858	32.34
Paris..........	Sand and gravel.	Maximum limit adopted.	1884	100,000	39,809	3,915	10.000	32.81
Medfield, Mass	Gravel.	Filtration without cultivation.	1887	108,543	43,209	4,250	10.854	35.61

* Apparently excessive.

It is seen from the above that the amount of sewage usually applied to land varies from 10,000 to 20,000 cubic meters per hektar per annum, falling nearly to 7,000 on heavy soil and rising to 33,000 with market gardening on a porous soil. That with 50,000 cubic meters per hektar per annum, the process becomes mainly one of filtration. That filtration has been continued with satisfactory results up to 100,000 cubic meters per hektar per annum, which is the maximum mentioned at Paris, and is a mean between the experiments at Paris and Medfield. These conclusions may be still further generalized by placing the amount to be used in market gardening at three times that used in ordinary irrigation, and the maximum for filtration at three times the amount for market gardening.

SELECTION, INSPECTION AND USE OF CEMENT AND MORTAR.

By S. F. Burnett, Member of the Engineers' Club of St. Louis.

[Read March 21, 1888.]

In this paper I shall endeavor to give a few practical hints in regard to the selection, inspection and action of cement and sand and the methods of mixing and using to produce a good mortar. As cement is the most important of these items I will consider it first. To obtain a good cement, what shall we specify for it and how shall we inspect it? The following conditions should be specified for it. It shall be of the very best grades of hydraulic cement, to be finely ground and put up in well-made casks and stamped with the maker's brand. It shall be subject to inspection and rigorous tests, and if found to be of improper quality it must be immediately removed from the work. Louisville cement shall stand a tension test of 90 pounds to the square inch, when allowed to set two hours in air and 48 hours in water. Portland cement shall stand a tension test of 300 pounds to the square inch, when allowed to set 24 hours in air and seven days in water. When stored, the cement shall be kept secure from moisture and currents of air.

The result of the test would be more satisfactory if the cement was given a longer time in water, but the difficulty of a long test is keeping cement enough on hand to last so long ahead.

It is almost impossible to make a contractor provide a shelter for cement that is any way secure from damp currents of air, moisture from the ground, and even rain. Hence a cement that is very good when tested may be poor by the time it is used, if too long a time is taken for testing.

Methods of Inspecting and Testing Cement.—It is often tested at the mill, where it is made as it is put up in barrels, but I very much prefer testing it on the ground where it is to be used. The simplest method of inspecting cement, and one that I have found to work nearly every time, is simply by examining the barrels. If the barrels are new and clean, without any marks on them, and the brand is one that you are familiar with, and know to be good; then it is pretty safe to say the cement is good. On the other hand, if the barrels are old and dingy, with holes plugged up in the ends of some of them, and marks on many of them, or if the barrels are old and the heads new, or newly scraped and newly branded; then beware of the cement, and do not let any of it be used until you have given it a full and rigorous test. Where the barrels are new and clean, and of a good brand, I would not be afraid to let the cement be used at once if I was in a hurry for it; but the regular modes of testing should be gone through with before the cement is used, if the time is not too pressing. This inspection of barrels applies only to Louisville cement. Nothing can be told from the barrels of Portland cement, nor from the brand either, as they vary so much.

This preliminary inspection of the barrels, etc., I consider very important, as it tells you just how to proceed with the tests that are to follow. We like to get a cement that is either very good or very bad. It is quite

aggravating to get a cement that comes up to the lowest limit allowed and no more. After one has tested cement for some time, it is a very simple thing to make five or ten pounds difference either way, at will, in the method of mixing. In most cases, the object in testing cement is not to get at the actual strength of the cement when properly mixed, but to find out if it will come up to the standard as specified, when mixed under its worst conditions. Then if you have a cement that you think is not very good, mix it accordingly, and if it then stands the test, it is safe to accept it, and if it does not stand the test, it is easy to reject it, as you have your record of what it stood.

In most cases the cement should be mixed as nearly to the same consistency and worked as nearly the same length of time as possible. The cement should be mixed to about the same consistency of the mortar for which it is to be used; it should be well worked for about a quarter of a minute. Very little more water added with less working will diminish its strength considerably. The following is a case showing about the extreme difference that can be made in the method of mixing. Sample of Louisville cement, Queen City Star brand; first sample was mixed very dry, or stiff, and pressed into the moulds, the second sample was mixed to ordinary consistency, and third sample was mixed very wet. All were allowed to stand ten days in air. The dry sample broke at 420 pounds; the ordinary one at 276 pounds, and the wet one at 115 pounds. The weights of these samples were 19, 18 and 15½, respectively, thus showing that the more cement in the section the stronger will be the section, other things being equal. With Portland cement the method of mixing does not make nearly so much difference. Portland cement will reject nearly all surplus water.

From the above experiment it will be seen how easy it is to make five or ten pounds difference at will. It is very necessary to have the moulds of exact shape, and great care should be taken in making the briquette; it should not be removed from the mould until it is hard and perfectly rigid. This care is necessary to insure a perfectly shaped briquette; if the briquette is not perfectly shaped the amount of its tension test will be considerably less. The cause of this is twisting in the clamps, pulling more on one side than on the other, or having too great a pressure near the edges of the briquette, causing the edges to chip off and thus causing the machine to jerk.

This method of testing *neat* cement, although about the best there is, is rather unsatisfactory, as the cement that is the strongest when mixed neat, is not always the strongest when mixed with sand. For instance, take any good cement and sift it through a No. 60 sieve. In nearly every case this sifted cement, when mixed neat, will not be as strong as the original unsifted cement mixed neat; but when each is mixed with one or two parts of sand, the sample having the sifted cement in it will invariably be the stronger. The following are a few cases to illustrate: Sample of fern leaf cement stood a test of 225 pounds, setting thirty days in air. This cement sifted through a No. 60 sieve, 75 per cent. passing through. Sifted cement stood a tension test of 217 pounds, setting thirty days in air; eight pounds less than original cement. Original cement, when mixed with two of sand, stood 33 pounds. Sifted cement, when

mixed with two of sand, stood 37 pounds. When mixed with one of sand the original stood 79 pounds and sifted 120 pounds, all setting thirty days in air. Another example: Queen City Star, setting two months in air, stood a tension test of 363 pounds. Sifted through No. 60 sieve, coarse stuff ground so as to all pass through, setting three months, stood 327 pounds. This cement then sifted through No. 130 sieve, coarse stuff being rejected, setting three months, stood 295 pounds. Original cement, with one of sand, stood 125 pounds. Sifted through No. 60 sieve, with one of sand, stood 126 pounds. Sifted through No. 130 sieve, with one of sand, stood 182 pounds, all setting three months in air.

From these experiments it appears that it is very desirable to have a finely ground cement, or more properly a cement with very little coarse stuff in it. This coarse stuff seems to be neither sand nor cement. It has no cementing power in its coarse state, but if ground it makes a poor cement. When present in cement in small quantities it acts about the same as a good sand. Consequently if it was not in the cement, just that much more sand could be added, and produce an equivalent mortar. The following is an example showing the action of this coarse material compared with sand. Queen City Star cement setting two hours in air and 48 hours in water stood a tension test of 129 pounds. This cement sifted through a No. 60 sieve, 81 per cent. passing through and 19 per cent. rejected; 19 per cent. of sand was then added to the fine portion and tested. It stood 125 pounds with the same time of setting. I then tried adding 19 per cent. of sand to the original cement. It stood only 92 pounds with same time of setting. The original cement with two of sand stood 56 pounds; the sifted cement with two of sand stood 80 pounds; both setting three months in air. This coarse material is a light substance, much lighter than the cement. It is probably ashes and the part of the stone from which the cement was made, that was not adapted to making cement. Portland cements contain very little of this material. Some of this coarse stuff from an excellent Queen City Star cement was ground, and passed through a No. 100 sieve, set three months, and stood 80 pounds. Original cement, setting 36 hours, stood 95.

Slow and Quick Setting Cements.—A slow setting cement generally becomes stronger in the end than a quick setting cement. They are much easier to use and for most work preferable. About the best cement ever tested by myself took sixteen hours setting before it was hard enough to remove from the mould. This cement, setting sixteen hours in air and twenty-four hours in water, stood 367 pounds. Same cement, setting sixteen hours in air and forty-eight in water, stood 451 pounds. A third sample of same cement setting thirty days in air stood 554 pounds. A sample of Indiana blue stone, with $\frac{4}{5}$ of the section stone and $\frac{1}{5}$ Portland cement, stood 560 pounds, only six pounds more than cement. Adding a very small quantity of sugar to cement retards the setting of it very much. A cement that will set in ten or fifteen minutes with pure water will take an hour to set if a little sugar be added to the water. Whether this increases the strength of the cement or not in the end I am not prepared to say. I am inclined to think that it does. I know it is weaker after setting eight days. But this is no reason why it should not be stronger after a month. If the sugar does not act chemi-

cally on the cement, then its mechanical action, by retarding the setting, should increase its strength.

From the foregoing we will assume that we can get a good cement. Having a good cement we will not get a good mortar unless we have a good sand and the two are properly mixed and worked with the proper amount of water. The sand is much easier tested than the cement. Its quality can always be determined by its looks, feel, etc. The sand should be clean and sharp (I do not think necessarily coarse, although it is generally so required). Both sharpness and cleanliness may be tested by taking a handful of the sand, in its moist state as it comes from the barge, and pressing it together with the fingers. If the sand is good it will not stick together but immediately fall apart when the pressure is relieved. If it sticks together it is probably loamy or dirty, and is not good. Sand may also be tested by crushing a handful near the ear; if it is clean and sharp it will have a grating sound. It may be further tested for cleanliness by washing a little in the palm of the hand; the hand should be left clean. It is almost as necessary to have a good sand as it is to have a good cement. The effect of poor sand is shown by the following, using the same cement and different sands: One of cement and two of good sand setting four months stood 73 pounds. One of cement and two of poor sand setting same time stood 60 pounds. One of cement and one of good sand setting four months stood 115 pounds. One of cement and one of poor sand setting four months stood 72 pounds.

Now, having a good cement and a good sand, it is still necessary to use much care in the mixing and using to get a good mortar. The water is also of some importance; it should be free from grease. In making mortar the sand and cement should always be measured, either in barrels or some other vessels, and not by the shovelful, as most mortar men want to measure it. An excellent method for measuring the sand is as follows: Knock both ends out of a cement barrel and cut it crosswise through the middle; set the half barrels in the mortar box, big end down, and fill them with sand; lift them off of the sand, and repeat the operation until enough sand is in the box for a barrel of cement. Then dump in a barrel of cement. The sand and cement must be thoroughly mixed while dry, until the whole mass is free from spots of cement or sand, and is of an even color throughout. The dry mixture is then shoveled to one end of the box, and water poured in the other end. The sand and cement is drawn down with a hoe, small quantities at a time, and well mixed with the water, until enough has been added to make a good stiff mortar. This should be vigorously worked with a hoe for several minutes, to insure a good mixture. The mortar should then leave the hoe or trowel clean when drawn out of it; very little should stick to the steel.

This mortar should then be used as quickly as possible. The consistency of the mortar depends somewhat on the kind of work on which it is to be used, and on the state of the atmosphere. For a material that absorbs very little water, such as granite, a stiff mortar should be used; for a material that absorbs much water, such as brick, a thinner mortar should be used. In cool, damp weather a stiff mortar should be used.

When a stone or brick is once well set in mortar (say for half an hour) it should not be disturbed; if it is necessary to move it, no matter how little, it should be taken up, the old bed of mortar scraped up and thrown away, not remixed and relaid, and a new bed of mortar laid.

In making mortar the amount mixed at a time depends on the rapidity with which it is used. It is very important that it should not be mixed faster than it is used; any mortar that has been mixed one hour is almost worthless. Using Louisville cement, the following are examples to illustrate: Fresh mortar setting three months stood a test of 60 pounds. Same mortar remixed after standing one hour, setting three months, stood only 33 pounds, 27 pounds less. Another case of fresh mortar setting four months stood 62 lbs. This mortar remixed after standing one hour setting four months stood 40 pounds, 22 pounds less. With a Portland cement, which is generally much slower setting, the mortar can be kept longer; but I think the sooner it is used after being well mixed and worked, the better the result. A cement mortar made of one of Louisville cement and two of good sand, should stand a tension test of not less than 50 pounds to the square inch when setting three months in the air. This is very low compared with some accounts of mortar made of German and English Portland cements with three of sand. A table published by Erskine W. Fisher, of New York, of German cements, the average of nine samples of different brands with three parts of sand, setting one month was 365 pounds. But we get no such cement or mortar here. The cement mortar used on the granite work of the new standpipe of this city averaged 64 pounds, setting four months. This average was of 16 samples taken out of the mortar box from which it was being used on different days. This is about as good mortar as is generally used. So much for the quality and strength of cement mortar.

Effects of Freezing.—In my experience I have found that freezing of mortar before it is well set always weakens it, at least. A mortar laid in freezing weather may turn out very good; but I do not think it is ever as good as it would have been had it been laid in warmer weather. If a mortar has a few hours to set before freezing (say during the day and freeze at night) the effect is not nearly so bad as if it should freeze as soon as laid. Again, if the mortar freezes as soon as laid or shortly after, and then remains frozen for several days (until it has dried) the effect is not so bad as it would be should it thaw within one or two days after freezing. The following are some experiments showing the effect of freezing. Sample of Queen City Star cement, mixed neat and setting in moderate temperature stood 421 pounds. Same cement allowed to set 15 minutes, and then frozen and kept frozen several days, stood 290 pounds. Same cement frozen as soon as mixed, and kept frozen several days stood 260 pounds. Same cement frozen as soon as mixed and thawed out next day, stood 88 pounds. All these samples set 2½ months in air. Sample of Black Diamond cement setting without freezing, stood 410 pounds. Frozen as soon as mixed, and left exposed to weather, stood 121 pounds. Frozen after setting 15 minutes, and left exposed to weather, stood 163 pounds. Frozen after setting 30 minutes, and left exposed to weather, stood 197 pounds. One of this cement, and two of sand, set without freezing, stood 142 pounds. One of this cement, and

two of sand, frozen after setting 1 hour, stood 65 pounds. From these experiments it appears that freezing of mortar before it is perfectly set, can do nothing but injure it.

Expansion and Shrinkage of Mortar.—The question has been asked several times; "Does mortar shrink or expand while setting?" I made a number of experiments to find out, and the result of my experiments is that I think it does neither to any appreciable extent. Mortar does swell, however, when immersed in water after it has set. This I proved beyond a doubt by filling a number of lamp chimneys with different mixtures of mortar, making duplicates of each mixture. After the mortar was well set I immersed one of each kind in water, leaving the other in air. In every case the ones immersed in water began to crack, some of them within one or two days after immersing, while others did not crack for one or two months. Most of them cracked all over, cross ways and every other way, so that some of them became a perfect network of cracks. A few of them had only one or two long cracks from one end to the other; these were the ones that cracked last. All the glass remained in place as long as the chimneys were kept in water, but when they were taken out and the mortar allowed to dry, nearly all the glass fell off; thus tending to show that the mortar shrunk back to its original size. In no case did the chimneys crack while left in air. Some of these, after setting four or five months in air, I put in water. They began to crack in the same manner as the others. This swelling seems to be somewhat similar to the swelling of wood when it becomes wet.

In no case did the mortar show any sign of shrinking before it had been immersed in water, or after being immersed in water, but only after it had been taken out it appeared to shrink back to its original size.

All statements made in this paper are based on the results of actual experiments. At least ten experiments of each kind were made and a conclusion drawn from the average of the results. The experiments given in this paper as illustrations are all average experiments.

I will end here my discussion of cement and cement mortar.

I will say only a few words in regard to lime mortar.

In the first place live mortar is a rather uncertain mixture. Limes differ about as much in quality and strength as cements, and have the disadvantage that they cannot be tested as cements, except by appearance; and a big disadvantage of lime is that too little sand added is almost as bad as too much. More or less sand than the proper amount will weaken the mortar. So unlike cement mortar it cannot be made safe by adding less sand. Again, this proper amount of sand can only be determined by the appearance and working of the mortar. Hence lime mortar is very uncertain unless made by a trustworthy and thoroughly practical mortar man.

The lime used should be fresh and in compact lumps, free from much dust of air-slacked lime. These lumps must be thoroughly slacked with water before being mixed with sand. The lime should be left in a moist state for several days at least, to insure a thorough slacking before adding the sand. It is claimed by some authorities that the longer the lime stays in this moist state the better.

Sand and water is added to and worked with this moist mass of slacked lime to make a mortar of the proper consistency; this should be vigorously worked with a hoe. When properly mixed and worked it should leave he hoe or trowel clean when drawn out of it. It is just as important to have a good sand as it is with cement mortar. Lime mortar, when everything about it is first-class, makes an excellent mortar, but it requires such care and skill to make all conditions first-class that it is seldom that a very good lime mortar is obtained.

BOSTON SOCIETY OF CIVIL ENGINEERS.

REPORT OF COMMITTEE ON WEIGHTS AND MEASURES,

COMPRISING A CANVASS OF THE SOCIETY REGARDING METRIC REFORM, WITH OPINIONS OF MEMBERS AND A NOTICE OF THE RECENT ACT OF CONGRESS.

[PRESENTED MARCH 21, 1888.]

To the Boston Society of Civil Engineers:

Your Committee on Weights and Measures was directed by vote of the Society at its regular meeting, Nov. 16, 1887, to make a canvass of the Society for the purpose of eliciting opinions regarding weights and measures, and of facilitating the expression of some response to the request of the Western Association of Architects (through their Committee on the Metric System), that this Society unite with them in petitioning Congress that the metric system be adopted by all the Departments of the Government for all Government business.

Your Committee has made the following analysis of the replies:

Questions.	Affirmative....	Negative.....	Doubtful.....	Total number of answers..	Percentage of affirmative answers....
(A). Whether it would be worth while ultimately to abandon many customary units, to secure uniformity and system in place of the existing irregularity ?......................	79	2	......	81	98
(B). Whether the uniform system of the United States ought ultimately to be as exclusively decimal in its ratios between units of the same class, as United States money is now ?......	73	8	......	81	90
(C). If the United States and foreign nations would all adopt the same system, whether the advantage to the United States over that of an equally good system peculiar to itself would be great enough to justify the United States in incurring a considerable increase of trouble and expense ?....................	68	9	2	79	86
(D). Is the ultimate exclusive adoption of the metric system throughout the United States desirable ?..................................	57	19	4	80	71
(E). As to the Boston Society of Civil Engineers, as a body, joining with the Western Association of Architects in a petition to Congress, as proposed by them, for the adoption of the metric system of weights and measures by the Departments of the United States Government ?........................	49	30	2	81	60
(F). Further opinions on weights and measures ?	......	......	......	......	....

Replies have been received from 83 members, or about 42 per cent. of the entire membership, which numbered 196 when the circulars were sent out. In some instances the replies did not contain answers to all of the questions.

The replies to question (F) are numerous, but are too diverse in character to admit of brief classification. They are valuable and worthy of consideration. Some of them are quite lengthy. All the replies have been deposited with the Secretary, and can be seen by any Member who may wish to examine them.

It appears to your Committee that this canvass should be interpreted on the basis of Articles XXI. and XXII. of the Constitution, which provide that no proposition which includes the Society's endorsement shall be passed except by a two-thirds vote passed in its favor at each of two successive regular meetings; or by the assent, in writing, of two-thirds of the whole number of immediate Members signified to the Secretary within one month preceding a regular meeting, and announced and recorded by him at that meeting.

Returns have been received from less than one-half of the membership, and it is therefore impracticable to draw absolute conclusions from these answers. It appears, however, to your Committee that, inasmuch as questions (A), (B), (C) and (D) have been answered affirmatively by more than two-thirds of those voting, they might receive the indorsement of the Society should formal action be taken; but that question (E), having been answered affirmatively by less than two-thirds of those voting, would not be likely to receive the indorsement of the Society.

Your Committee therefore concludes that it is not the wish of this society to unite as a body with the Western Association of Architects in a petition to Congress, as proposed by them, for the adoption of the metric system of weights and measures by the Departments of the United States Government.

Respectfully submitted,

CHARLES H. SWAN,
CHARLES W. KETTELL, Committee.
BOSTON, March 20, 1888. CHARLES W. FOLSOM,

SUPPLEMENTARY REPORT—THE RECENT ACT OF CONGRESS.

Since the presentation of the Committee's report, Congress has made an enactment (approved by the President, May 24, 1888) which is likely to be decisive as to the adoption of the metric system in our Custom Houses. It authorizes the President of the United States to invite the several Governments of the Republics of Mexico, Central and South America, Hayti, San Domingo, and the Empire of Brazil, to join the United States in a conference to be held at Washington at such time as he may deem proper in the year 1889, to consider, among other things, the formation of an *American Customs Union*, and the adoption of a *uniform system of weights and measures*. The tendency of this may be understood from the facts that each Government is to have a single vote; that, with insignificant exceptions, if any, the nations south of the United States already use in their Custom Houses the metric system, which the United States has fully legalized; and that the United States, Venezuela, Peru, and the Argentine Republic concluded with the

European nations the metric convention of May 20, 1875, establishing the International Bureau of Weights and Measures, under the control of a General Conference for Weights and Measures, whose duty it is "to discuss and initiate measures necessary for the dissemination and improvement of the metric system." We have the testimony of engineers from the United States that the metric system is used on public works in the principal countries of Central and South America.

For the Committee,

BOSTON, May 26, 1888. CHARLES H. SWAN, Chairman.

APPENDIX.

After the reading of the report to the Society, it was voted March 21, 1888, that the Committee be authorized to print such portions of the replies to question (F) as seem desirable. Your Committee has accordingly made the following selections :

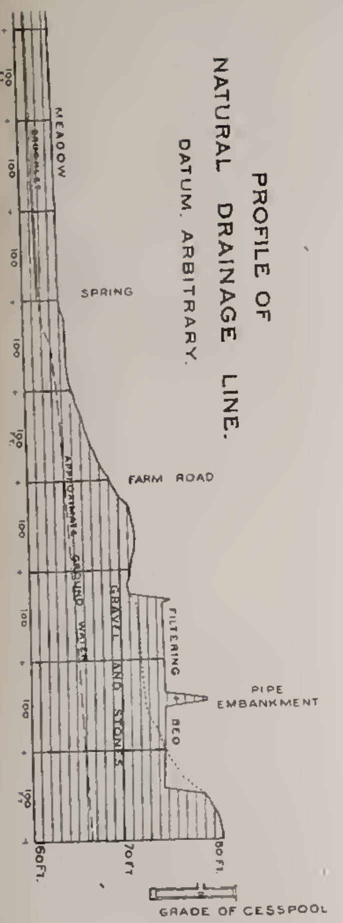
TYPICAL EXTRACTS FROM THE REPLIES.

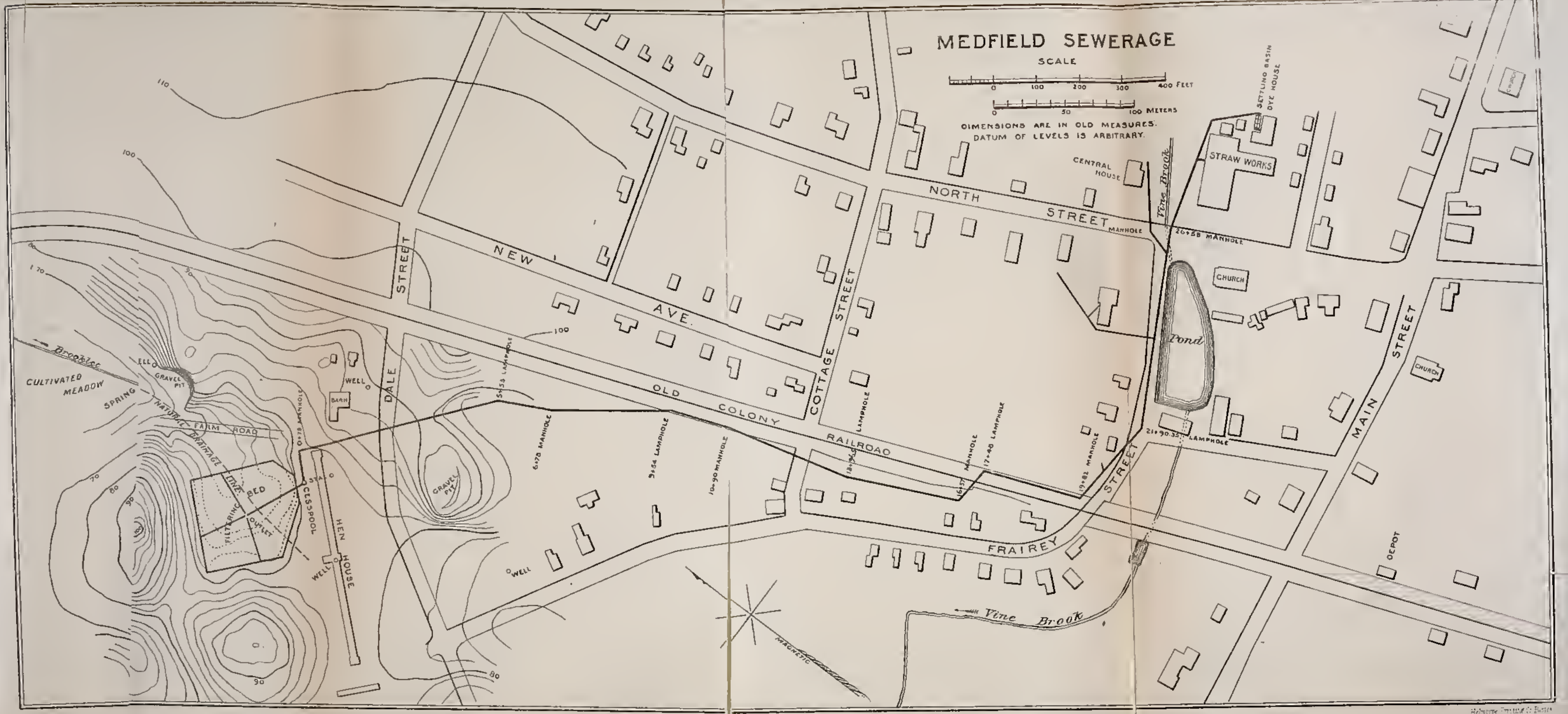
No. 1. I am most emphatically opposed to the whole business. * * * In my opinion it is utterly and absolutely impossible to introduce the French system of weights and measures, with all its interminable decimals, into either England or the United States. * * * I oppose the French metric system because of its intrinsic defects. The meter is not a unit of length needed in this country for any of the practical operations of business or in the arts. * * * The decimal division is very convenient for some purposes, but for others it is absolutely useless. The half, quarter, eighth, sixteenth, etc., are the natural divisions of everything. * * * The meter was founded upon a myth, and its originators made a serious mistake in getting the original distance that its value was based upon.

No. 2. (From a member in practice with a mechanical corporation). Personally, I am not opposed to the introduction of the metric system. Although now perfectly familiar with our present system of halves, quarters, and eighths, in measures of length, I have no doubt a very short time would be sufficient for me to make myself at home with the metric system; the advantages of which are less apparent, or less marked in my present business. In fact, I do not doubt that many professional men would find it much more valuable to them than our present system. But I do not know of any errors or costly mistakes or business disadvantages than can be fairly charged to the present system; and I do not feel justified in asking my present superiors (who are single examples of what must be a very large class) to subject themselves to the great annoyance, the increased liability to mistakes, and the large increase in expense, all of which would follow such a change as is proposed to be eventually made.

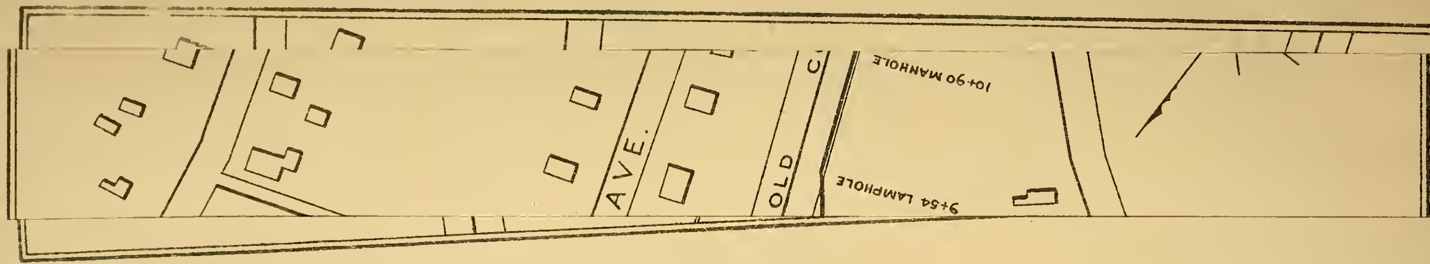
No. 3. * * * I am entirely in favor of a decimal system throughout. My objection to the metric system is found in the unit; and it is the outcome of my practical field experience in Mexico, where the metric system was used. * * * I prefer a shorter unit.

No. 4. * * * I am glad the question has been brought up. I should like to see published, for the benefit of the Society, the arguments for and against the metric system, provided it would be done so as to give the fullest and best arguments on both sides. * * *


PROFILE OF
NATURAL DRAINAGE LINE.
DATUM. ARBITRARY.
MEADOW
SPRING
FARM ROAD
FILTERING
PIPE
EMBANKMENT
BED
GRAVEL AND STONES
60 FT.
70 FT.
80 FT.
GRADE OF CESSPOOL


MEDFIELD SEWERAGE
SCALE
400 FEET
100 METERS
DIMENSIONS ARE IN OLD MEASURES.
DATUM OF LEVELS IS ARBITRARY.
NORTH STREET
NEW AVE.
OLD COLONY RAILROAD
COTTAGE STREET
DALE STREET
MAIN STREET
FRAIREY STREET
CENTRAL HOUSE
STRAW WORKS
SETTLING BASIN
DYE HOUSE
CHURCH
Pond
Vine Brook
Brooklet
CULTIVATED MEADOW
SPRING
GRAVEL PIT
NATURAL DRAINAGE LINE
FARM ROAD
FILTERING BED
OUTLET
CESSPOOL
HEN HOUSE
BARN
WELL
MANHOLE
LAMPHOLE
DEPOT
MAGNETIC

E I.



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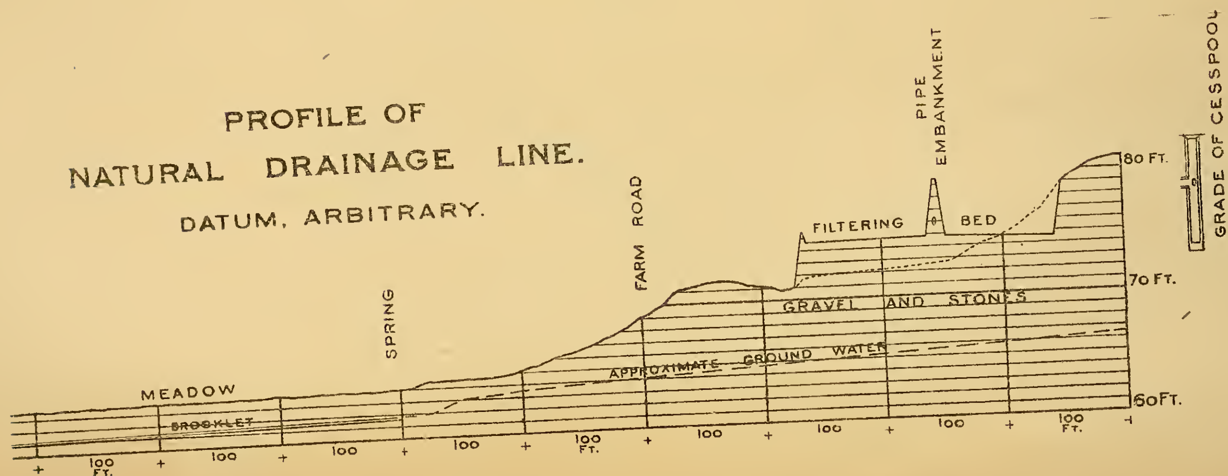
PROFILE OF
NATURAL DRAINAGE LINE.
DATUM, ARBITRARY.



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ASSOCIATION OF ENGINEERING SOCIETIES.

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SEWAGE DISPOSAL AT MEDFIELD, MASS.

BY FRED. BROOKS, MEMBER OF THE BOSTON SOCIETY OF CIVIL ENGINEERS.

[Read February 15, 1888.]

The following is a very slight modification of the account of the sewerage of Medfield, prepared by the writer and published in 1888 in the nineteenth report (for 1887) of the Massachusetts State Board of Health, to whom acknowledgment is due for facilitating the present publication.

Medfield is an old town on Charles River, seventeen miles from Boston. Its population in 1885 was 1,594; valuation, $1,110,858; receipts and expenditures, about $18,000 each: so that relatively to the size of the place the sewerage here described, which cost but a few thousand dollars, is comparable with the costly sewerage works of great cities. The business of Medfield is mostly agricultural, the principal exception being the Excelsior Straw Works in the middle of the town, employing in the busy season six or seven hundred operatives, but during about five months in the summer and fall, less than half as many. The general plan folded herewith (Plate I.) will enable the character of the work of sewerage to be understood with the aid of a brief description.

The straw works drainage, nearly half of which comes from the vats in which straw is dyed, used to run into Vine Brook, which flows past the works and is dammed up in a small pond just below, whose level is frequently raised and lowered for mechanical purposes. This produced an offensive smell around the pond, and blackened and polluted the water so that some residents below on both sides of the brook immediately west of the railroad track, who had used its water for domestic supply, were obliged to abandon it, and made several complaints. In 1886 a pipe sewer was built chiefly for the purpose of keeping the sewage from the straw works out of Vine Brook, and disposing of it so as to avoid the nuisance. The sewer has been entered also by the Central House (having accommodations for about forty boarders), which formerly drained into the brook, and by three private dwelling houses which did not drain into the brook. As a result the channel of the brook has already

been washed so that it is inoffensive to sight and smell. A favorable place was found a little out of the village for the discharge of the sewage and its purification by intermittent downward filtration.

The work was projected by Eliot C. Clarke, C. E., and the details of its execution were put under the charge of the writer. The plans were presented to the State Board of Health in August, 1886, and were approved by the Board.

Much ground dye-wood is used at the straw works, and if this in its water-logged condition were admitted to the sewer it was not to be supposed that the sewer would be self-cleansing with the gradient available. It falls at the rate of 4 per 1,000 for nearly a quarter of a mile (400 m.). Accordingly to exclude the spent dye-wood from the sewer there was built adjacent to the dye-house a settling basin with a filter, whose construction may be understood by the aid of the accompanying drawing (Plate II.). It is made in two parts, side by side, exactly alike, in order that one-half may be in use, if necessary, while the other is being cleaned out. The discharge from the vats can be turned by a wooden gate in the trough which brings it from the dye-house into either side of the settling basin separately. Entering by the four-inch (10 cm.) openings the liquid flows generally in both sides with a total width of ten feet (3 m.) and a depth of four feet (1.2 m.) less the thickness of the deposit of sediment. The velocity of flow is thus checked, and the ground dye-wood has a chance to settle. To get into the second pair of compartments it has to pass over the brick dividing wall, whose elevation is the same as the bottom of the inlet pipe. Here is another opportunity for settlement to take place, but apparently very little collects in the second compartments until the first are pretty well filled. In the third compartments by a tight board partition the liquid is obliged to pass downward, and escape by upward filtration through a mass of excelsior held between two sets of wooden slats, as exhibited by the drawing; the upward flow being preferred, as a precaution against choking the filter. The filter was in use nearly a year before the excelsior was changed; it worked very satisfactorily, but the excelsior had by that time become so rotted that probably it would soon after have gone to pieces and escaped through the sewer. A new supply was accordingly substituted. The sediment needs to be shoveled out and carted off once or twice a year; it has a similar appearance to saw-dust, except for its black color.

From the settling basin the sewer of Akron vitrified clay pipe runs four inches (10 cm.) in diameter to where other drainage of the straw works enters from the water-closets, sinks, bleachery, etc. There it enlarges to six inches (15 cm.), which is the diameter as far as the North street man-hole. The portion above mentioned, and also the branches to houses, were built at private expense. From the North street man-hole the main sewer was built by the town of Medfield as a common sewer, intended to admit sewage from shops and houses, but to exclude rain water entirely. It is eight inches (20 cm.) in diameter, and has capped branch pieces set at several points to admit of ready extension of sewerage through the thickly settled parts of the village, if required in the future. The sewer is low enough to do this, as it passes under Vine Brook at North street; for some distance both above and below

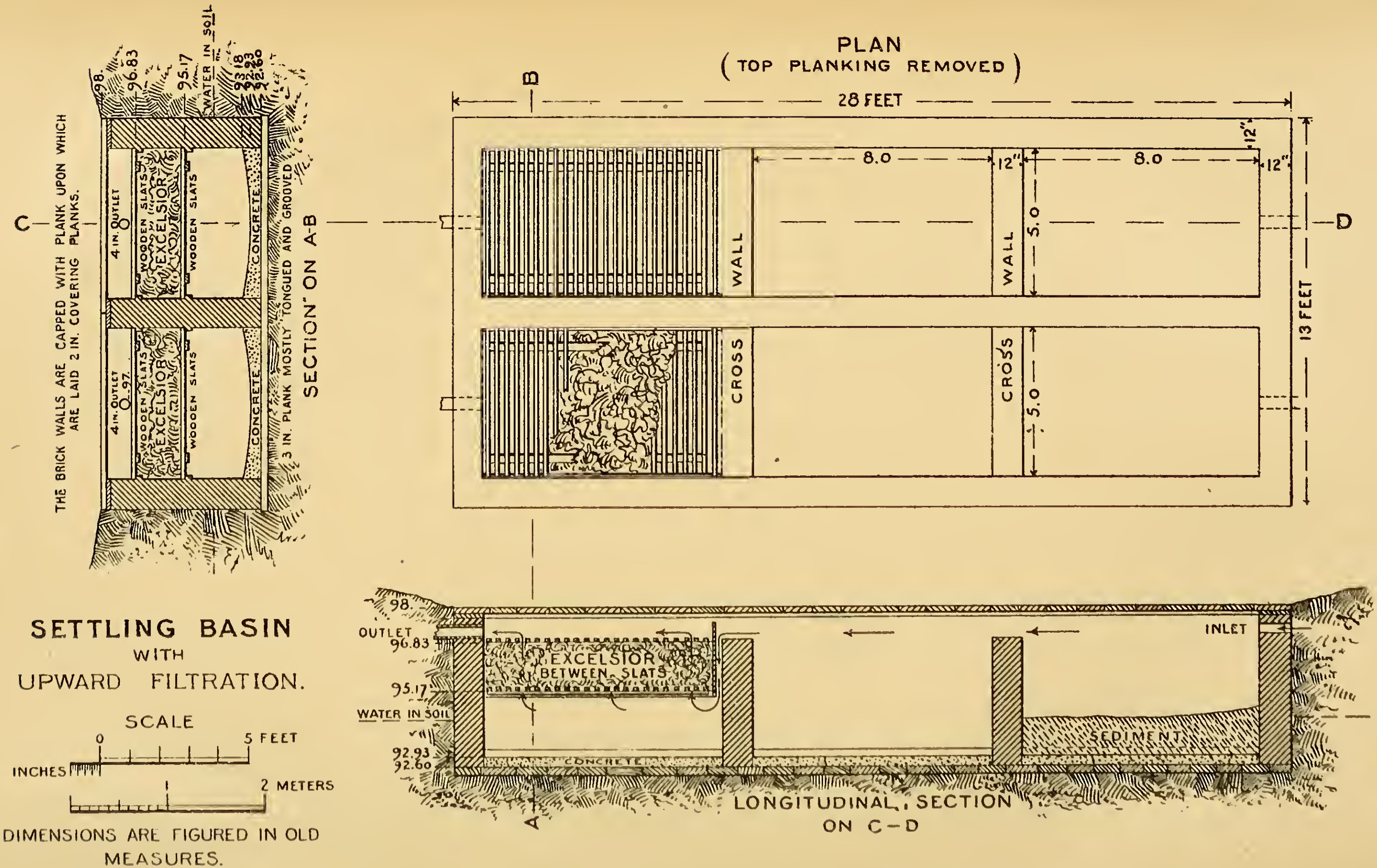
THE BRICK WALLS ARE CAPPED WITH PLANK UPON WHICH ARE LAID 2 IN. COVERING PLANKS.
C
4 IN. OUTLET
97.
WOODEN SLATS
EXCELSIOR
WOODEN SLATS
CONCRETE
3 IN. PLANK MOSTLY TONGUED AND GROOVED
98.
96.83
95.17
WATER IN SOIL
93.18
92.93
92.60
SECTION ON A-B
PLAN
(TOP PLANKING REMOVED)
28 FEET
B
8.0
12"
CROSS
WALL
5.0
13 FEET
D
OUTLET
INLET
EXCELSIOR BETWEEN SLATS
SEDIMENT
CONCRETE
A
LONGITUDINAL SECTION ON C-D
SETTLING BASIN
WITH
UPWARD FILTRATION.
SCALE
0
5 FEET
INCHES
2 METERS
DIMENSIONS ARE FIGURED IN OLD MEASURES.

PLATE II

that point it is below the level of the water in the soil. Three lengths of pipe under the brook (thirty-six feet or eleven meters in all) are of iron, with lead joints, and are probably tight. The rest of the sewer is laid with Akron pipe, jointed with cement mortar; and although it was intended to be as tight as a bottle, it in fact admits water from the soil, both above and below the brook crossing. The quantity thus leaking in was approximately estimated, before sewage was admitted, by pumping out all that came to the North street man-hole and determining the rate of pumping by observing how long it took to fill a pail; also by measuring at the same time the depth of the water flowing in the sewer at the man-hole by the railroad bridge. It was estimated a year later by observing the minimum flow, as on holidays, when little sewage is running. The quantity appears to be about 2,000 cubic feet (57 m^3) per 24 hours, and does not appear to have increased or diminished materially. This leakage is likely to continue until a portion of the Akron pipe is replaced by iron pipe.

The sewer does not fall at so rapid a rate as Vine Brook, and after passing close beside the pond the rest of the sewer is laid in dry gravel. The line of the sewer diverges more and more from the brook, and as it approaches Dale street it passes out of the water-shed of Vine Brook. It is laid in straight lines, and has a man-hole and a lamp-hole alternately at each angle.

Near the lower end of the sewer the sewage passes through a cesspool arranged as shown on the accompanying drawing (Plate III.), so that the outflow takes place from beneath the surface of the sewage standing in the cesspool. The effect is that objects which either float or sink are held back until they are sufficiently changed by chemical or other action to flow uniformly with the rest of the liquid, and are prevented from being thrown out upon the ground at the outlet, where lumps of fœcal matter, orange peel, and the like might be offensive or ill-adapted for percolating through the ground. Very little sediment collects in the cesspool. The T-branch piece, however, at the cesspool outlet was not put on as required for about a year, during which time the sewage was allowed to run through without interruption of its surface; and presumably in consequence of this neglect, the outlet of the cesspool was once stopped up by some floating substance. When after this delay of a year the T-branch was set, sediment about a foot (0.3 m.) deep was found in the cesspool. To empty the cesspool for setting the ⸢, a pump was used powerful enough to dispose of all the sewage running. This sewerage work is on so small a scale that it is possible to do without a by-pass such as would otherwise be needed to take care of the sewage flowing during any repairs or cleansing at the cesspool. In this case the sewer could be plugged up temporarily at the first man-hole, 75 feet (23 m.) from the cesspool; if the plug were at the upper side of the man-hole the sewer could fill for a few hours before overflow could take place at the first lamp-hole, 553 feet (169 m.) from the cesspool: if the plug were at the lower side of the man-hole the sewage could run out upon the ground adjacent to the filtering bed, as the man-hole is only 2 or 3 feet (0.8 m.) deep. As to ventilation, there appears to be some danger that in case the wind should blow directly into the mouth of the sewer, pressure might

be produced at the house connections, although the writer is not aware that any trouble has arisen; to obviate the supposed danger it might be well to bore a few holes in the wooden covering of the cesspool, or better to extend the upward end of the T-branch piece through it.

The average velocity of the sewage is about 1.7 feet (0.5 m.) per second, for it takes about half an hour for it to pass from the dye-house through the sewer, which is nearly 3,200 feet (1 km.) in extreme length, to the outlet, where it flows out upon the surface of the ground. This disposal of it is the principal subject of interest about the work. The filtering bed upon which the sewage is discharged consists of one acre (4,000 m.^{2}) of ground graded nearly level. It was intended to be conical, sloping at the rate of five per thousand away from the center, where the outlet of the sewer is; but owing to slight imperfections in the work, unequal settlement, etc., it is a little irregular,—generally flatter. Material was excavated from the higher exterior portion of the site selected and filled in upon the lower portion, so as to balance the cutting and filling, as may be seen by the accompanying profile of the natural drainage line, and by the general plan, which exhibits by dotted lines the original contours of the ground. The amount of material moved was 2,000 cubic yards (1,500 m.^{3}); the distance, very short. The shape of the filtering bed was made a little irregular to adapt it to the existing topographical conditions; but it is substantially a square, subdivided into four small squares of one-quarter acre (1,000 m.^{2}) each by little embankments, three of which are about a foot (0.3 m.) in height; the fourth covers the pipe to a depth of three feet (0.9 m.), for protection against freezing or other injury. To prevent the sewage from running off from the filtering bed without penetrating its surface, the filling was also embanked about a foot (0.3 m.) above the graded surface along the northeast side of the filtering bed, the only portion of the exterior line where the graded surface was not lower than the ground adjacent. The material is mostly gravel and stones from the size of a man's fist downwards, and is well suited for the purpose of filtration. In grading the filtering bed the thin stratum of loam and grass upon the surface was not removed; it was simply ploughed up and then handled like the gravel. But the narrow strip under the embankment through which the pipe is laid, had its loam stripped off, and the gravel with which it was replaced was carefully puddled to make an unyielding foundation for the pipe. At the middle of the filtering bed the pipe sewer ends, as shown on Plate III., in a wooden trough having four outlets,—one to each subdivision of the filtering bed,—which outlets are closed by three gates; so that the sewage runs on to one subdivision, and is shut off from the other three. Every other day the gate is changed from one outlet to the next, so as to turn two days' sewage on to a subdivision, and then give it six days' rest, to allow the sewage to pass off through the ground, and let the surface of that division become dry enough for another dose. If such a filtering bed were so located as to be washed by the rainfall on any considerable area it might be protected by an intercepting ditch around the upper side.

No underdrainage has been put in at the filtering bed. The ground water naturally is about ten feet (3 m.) below the surface of the filtering bed. Judging from the visible indications, especially the contour of the

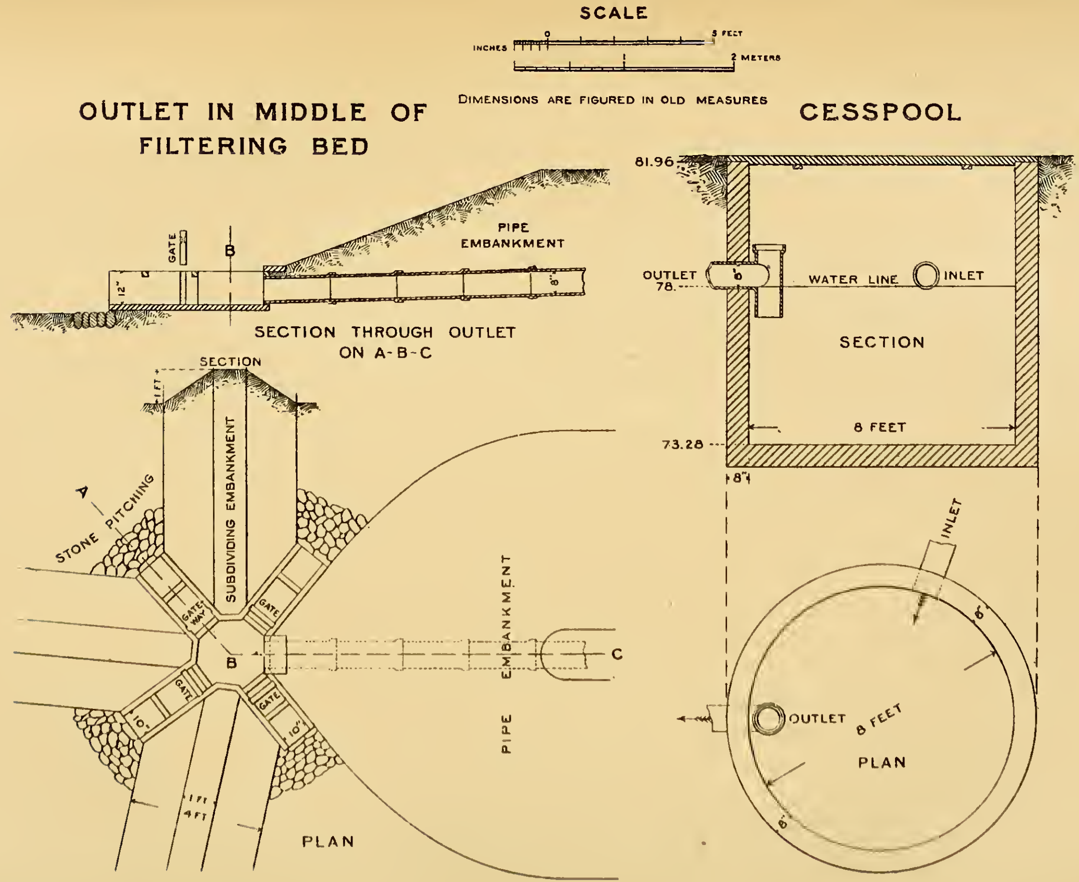
SCALE
INCHES
0
5 FEET
1
2 METERS
DIMENSIONS ARE FIGURED IN OLD MEASURES
OUTLET IN MIDDLE OF FILTERING BED
GATE
B
12"
8"
PIPE EMBANKMENT
SECTION THROUGH OUTLET ON A-B-C
SECTION
1 FT
SUBDIVIDING EMBANKMENT
A
STONE PITCHING
GATE WAY
GATE
GATE
GATE
10"
10"
B
C
1 FT
4 FT
PIPE EMBANKMENT
PLAN
CESSPOOL
81.96
OUTLET 78.
6"
WATER LINE
INLET
SECTION
8 FEET
73.28
8"
INLET
6"
OUTLET
8 FEET
PLAN
6"

PLATE III

surface of the ground, the natural drainage from the filtering bed must be in the direction of a little depression leading down toward the meadow to the northward, where there is a spring of very good water which is the source of a permanent stream, as shown on the plan and profile. The artificially straight course of the little stream may be explained by the fact that the meadow through which it flows was graded up several years ago, so that better crops could be cultivated. This stream being a tributary of Charles River, upon whose banks a long distance below are situated the filtering galleries from which several municipalities draw their water supply, Medfield sewage requires to be purified before entering it. To determine as to the purification accomplished, chemical and biological examinations of the spring water and other water in the vicinity have been made by the State Board of Health, as shown in the tables herewith.

The samples of sewage were taken from the outlet in the middle of the filtering bed. To determine the quality of unpolluted ground water, samples were taken from several wells in the vicinity, whose positions are shown on the plan. Much the most useful one for the purpose is the one (Nos. 1,296 and 1,666) near the spring, from which it is 78 feet (24 m.) distant: the surface of the water in this well was observed to be about 1 $\frac{7}{10}$ feet (0.5 m.) higher than the spring. Moreover, the contour of the ground would lead one to suppose that the natural direction of percolation under ground is from the well toward the spring. There are no buildings near and the well is out of use. The spring existed before the sewerage, and has a considerable water-shed to draw from; but that some of the effluent from the filtering bed now mingles with its waters is very plain from the analyses, the first of which was made after the works had been in operation nearly nine months; the excesss, in all the analyses, of residue, chlorine and nitrates in the spring-water, as compared with the well-water, and also their variation in the different analyses of the spring-water show it. As the proportion of chlorine in the spring-water is not far from a mean between that in the well-water and that in the sewage, it may be inferred that somewhere about half of the flow from the spring comes from the sewage and about half from the soil, for it is found that chlorides pass through sand filters unchanged. The quantity of water flowing visibly from the spring appears to be less than is discharged from the sewer, so that a portion of the outflow must take place beneath the ground. The comparison of the sewage and spring-water analyses in respect to ammonia and nitrates shows not mere dilution, but purification; the free ammonia and albuminoid ammonia, found in large quantity in the sewage, represent organic nitrogenous matter; oxidation converts the nitrogen into the inorganic form of nitrates, and it is these which are found in the spring-water in very much greater proportion than in the sewage, while from the spring-water the ammonia has almost disappeared. In respect to ammonia, the spring-water compares favorably, not only with well-water, as given in this table, but with public water supplies, including many that are drawn from the ground. Neither sight, taste nor smell detects anything objectionable in the spring-water. That purification takes place in winter as well as summer is shown by the last analysis, January 23, 1888.

ANALYSIS OF WATER AND SEWAGE AT MEDFIELD, MASS.

(Parts in 100,000.)

Wells presumably Unaffected by the Filtering Bed.

Number.	Date, 1887-88.	Appearance.		Odor.		Residue on Evaporation (Unfiltered).				Ammonia.		Chlorine....	Nitrogen as nitrites & nitrates ..	Nitrites	Elevation of water surface. Feet
		Turbidity.	Color.	Cold.	Hot.	Total	Loss on ignition	Fixed	Odor on ignition.	Free.	Albuminoid				
1034	Oct. 25.	Slight. Some grassy, flocky sediment.	None.	Very faint or none.	Very faintly wooden.	7.70	1.20	6.50	Slightly disagreeable.	.0132	.0148	.47	.150	None.	..
1035	Oct. 25.	Very slight. Considerable earthy and flocky sediment.	None.	Distinctly straw-like and somewhat mouldy	Distinctly musty.	9.47	2.95	6.52	Acid and somewhat disagreeable.	.0000	.0116	.70	.520	None.	66
1036	Oct. 25.	Very slight. A little light flocky sediment.	None.	Very disagreeable.	Very disagreeable.	4.40	0.45	3.95	Very faint or none. White residue.	.0000	.0060	.27	.008	None.	66
1296	Nov. 30.	Slight. Much earthy and dark brown flocky sediment.	Very faint.	Very faint or none	None.	5.60	0.70	4.90	Faintly acid.	.0014	.0054	.42	.003	Present	63
1666	Jan. 23.	Clear. Very little sediment.	None.	None.	Very faint or none.	4.50	0.90	3.60	Faintly acid.	.0000	.0033	.38	.065	Present	63

Sewage.

Number.	Date, 1887-88.	Turbidity.	Color.	Cold.	Hot.	Total	Loss on ignition	Fixed	Odor on ignition.	Free.	Albuminoid	Chlorine....	Nitrogen as nitrites & nitrates ..	Nitrites	Elevation of water surface. Feet
1033	Oct. 25.	Opaque.	Black.	Sewage.	Sewage.	45.90	16.00	29.90	Acid and offensive.	.0200	.3860	1.48	....	....	75
1294	Nov 30.	Opaque.	Black.	Sewage.	Sewage.	90.30	46.80	43.50	Very offensive.	.8520	1.570	2.67	.008	....	75
1667	Jan. 23.	Opaque.	Blue bl'k	Sewage.	Sewage.	62.50	18.50	44.00	Very offensive.	.4240	.3180	2.60	.015	Present	75

Spring Containing Effluent from the Filtering Bed.

649	Aug. 29.	Clear.	None.	Faintly straw-like.	Very faint or none.	11.80	0.95	10.85	Peaty. Brown residue.	.0006	.0026	1.14	.195	None.	62
1295	Nov. 30.	Clear. No sediment.	None.	Very faint or none.	None.	16.00	3.10	12.90	Decidedly acid.	.0000	.0024	1.63	.250	None.	62
1665	Jan. 23.	Clear.	None.	None.	Very faint or none.	15.40	2.60	12.80	Faintly acid.	.0004	.0043	1.33	.300	Present	62

No. 1034.—From well in hen-house. It had not been used since about Sept. 6, 1887, on account of failure of pump. This sample was taken immediately after repairs of pump. Disinfectant is used in the hen-house and is very conspicuous to the smell.

No. 1035.—From well near Frairey street not recently used. Half a pailful of water from another source was poured in to moisten the valves of the pump.

No. 1036.—From well near the barn.

Nos. 1296 and 1666.—From disused well near spring. Water is shallow, and it is not easy to get sample without some sediment.

No. 1033.—About twenty people in the straw works. Some vats were emptied at the dye-house at a time to contribute to this sample. Of the residue on evaporation, 8.80 parts in 100,000 were suspended matters; 37.10 parts in 100,000 were in solution.

No. 1294.—Dye-house and bleachery in full blast. About 400 people in the straw shop. Of the residue on evaporation, 10.90 parts in 100,000 were suspended matters, 79.40 parts in 100,000 were in solution.

No. 1667.—About 750 people in the straw works. Work more active than ever before.

Nos. 649, 1295 and 1665.—The temperature of the spring water, Nov. 30, 1887, was 8° C., that of the air being — 1° C.; on Jan. 31, 1888, it was 5° C., that of the air being — 3° C.

BIOLOGICAL EXAMINATION.

Samples collected Feb. 24, 1888, were tested by the method of plate culture, and the number of bacteria per cubic centimeter was estimated thus:

In water from disused well near spring	98
In sewage from the sewer outlet (3 samples)	1,046,400 to 1,320,000
In water from the deepest part of the spring (2 samples with 21 minutes interval)	560 and 114
" " " brooklet, 40 feet (12 m.), down stream from the spring	17,531

Surface water was running into the spring and into the brooklet along 40 feet (12 m.) of its course below the spring; this probably accounts for the difference between the two samples from the spring, and for the enormously greater number of bacteria from the brook sample. Stable manure was spread over the meadow in the fall of 1887.

The success of this filtering bed during the severe cold of winter has been favored by the fact that the dye vats are kept at a high temperature. Daily observations in October, November, December and January, 1887–88, show that the temperature of the sewage as it comes upon the filtering bed at the outlet is, while business is active at the straw works, generally from 15 degrees to 27 degrees C., falling at night and on holidays from that downward to about the temperature of the ground water, say 10 degrees C. In January, 1887, on a day when the thermometer went down to 32 degrees below zero C., the sewage was turned on to a division of the filtering bed that was covered with snow and ice. The writer visited it a few days later, and found that from a strip five or ten feet (2 or 3 m.) wide, extending nearly across the bed, the snow and ice had been melted away. The sewage had also run underneath the remaining snow and ice a little way, so that on digging with a shovel through it—say ten feet (3 m.) from this open place—moist and unfrozen ground was found beneath ; still further away, the ground was frozen. On January 31, 1888, shortly after a period of severe cold, there was a large sheet of ice strong enough to walk upon, between which and the moist surface of the ground was a void space of about 0.4 foot (12 cm.) in depth, showing conclusively that after collecting in a pond the sewage had soaked away into the ground.

With regard to the quantity of liquid discharged upon the filtering bed, it was estimated in the latter part of 1887 by putting a little weir at one of the wooden trough outlets and observing at intervals the height of water going over it. It fluctuates a great deal, but it is estimated that (including a leakage of 1,000 cubic feet [28 $m.^3$] per 12 hours of clean water. above spoken of) on 180 working days there is an average flow of 4,000 cubic feet (113 $m.^3$) in 12 hours; on 120 working days, of 2,500 cubic feet (71 $m.^3$) in 12 hours, and on 65 holidays and 365 nights, of 1,250 cubic feet (35 $m.^3$) in 12 hours. That this estimate (though not claiming to be minutely accurate) is substantially correct may be judged by comparing such estimates as can be made from known facts as to the number of people in the buildings and the quantities usually discharged from the dye-house and bleachery ; also by comparing the estimated quantity of water pumped from an artesian well which is the original source of most of the liquid that gets into the sewer. Most of what is pumped from this well ultimately finds its way into the sewer. More has been pumped heretofore than the required water supply, and the excess has been allowed to overflow from a tank and escape into the sewer, making just so much unnecessary hindrance to the drying of the filtering bed ; whereas, if pumped at all, it might better have overflowed into Vine Brook, being pure water. For purposes of comparison the quantity of liquid discharged upon this filtering bed of one acre (4,000 square meters) may be estimated at 4,250 cubic feet (120 cubic meters) per twenty-four hours the year round, though the actual want of uniformity must make the effect rather different. For the purpose of comparison as to the population provided for, we may assume, as an approximation, that the manufacturing waste from the straw works takes the place of the domestic waste that would ordinarily go with the number of operatives that board outside of the sewered area ; and thus counting operatives

and residents alike, may call the average population provided for about 500.

The works were designed for about 3,000 to 3,500 cubic feet (about 90 m.^{3}) of sewage per twenty-four hours ; but the town secured an additional acre (4,000 m.^{2}) of ground around the present graded filtering bed with a view to extending its area, if an increase in the quantity of sewage to be disposed of should hereafter make it necessary. At present the full area prepared is not fairly availed of, because from the neglect to grade the surface more accurately by a litttle harrowing there are portions which stand high and dry and have never been touched by the sewage, which collects in the low places where, after two days' discharge, it stands in a pool. The six days following hardly give sufficient opportunity for it to percolate through the soil, and for the surface of the filtering bed to become dry. The natural tendency is toward the formation of a moist, pasty coating over the surface of the lowest points of the filtering bed, entirely contrary to the intention with which it was laid out. In spite of this imperfection, which it is not to be supposed will be allowed to continue, the general working of the scheme has been highly satisfactory. No smell is noticeable except just at the outlet of the sewer. Some weeds and grass have sprung up on the higher portions of the filtering bed ; there has been no intention of cultivating it.

The work for the town was done under a contract for a "lump" sum ; the cost of the disposal works was probably about $1,000, including cesspool, pipe from cesspool to outlet, earthwork, engineering, superintendence and profit to contractor, and the value of the land, which was given to the town. The annual expense of maintenance of the work of disposal is insignificant—probably about thirty dollars. A man has to change the gate regularly, which is the principal labor required. The surface ought to harrowed over when it gets clogged with sediment, the embankments repaired if they get trodden down or washed, the wooden parts will have to be occasionally renewed as they decay, the cesspool will have to be emptied sometime ; but a very few days' labor annually will cover all that appears to be required.

To conclude, these works on a small scale furnish an instructive example of the feasibility of disposing of sewage upon land under favorable conditions without nuisance, with very slight annual expense, and with thorough purification of the effluent. The successful working in the winter of this sewage disposal is somewhat less valuable as a precedent for other places, because of the exceptionally high temperature of this sewage.

DISCUSSION.

Mr. F. P. Stearns : I visited the sewage disposal area of the State institutions at Cranston, R. I., on the 28th day of January, 1888. The temperature of the air in the morning was —19.4° C. (3° below zero F.), and at one P. M., at the time of the visit, —15.6° C. (4° F.). This was one of the coldest days of the season, at the end of a very cold week, and near the end of the coldest January since 1857.

The population of the institutions contributing sewage was about 1,000, and the mean flow about 90,000 gals. per day. The sewage was being turned upon a level tract of about 2.5 acres. The surface of the ground

was generally covered with ice about 5 inches thick. Near where the sewage went upon the field it was not frozen. Beyond this it appeared to be flowing over the ice, and a new layer was forming upon the surface of the sewage. To all appearances very little sewage was entering the ground. It is evident, however, either that the sewage did enter the ground, or that it had been filtering through prior to this time, as the total accumulation of ice upon the surface did not represent more than 8 days' flow of the sewage, and a large portion of it was probably due to rain and snow, the precipitation for the month having been 4.5 inches. The areas were so arranged that no sewage could run off over the surface.

The conditions prevailing at this time made this a very severe test of sewage disposal in winter, yet the results seemed to be very satisfactory, notwithstanding the apparent freezing of nearly all of the sewage on the day of the visit. There was no odor, no sewage running off unfiltered into the streams, and but little had accumulated in the form of ice.

Not only was the weather very cold, but the temperature of the sew- 4.7° C. (40.5° F.), was unusually low. The average temperature of Medfield sewage in January, 1888, as deduced from daily observations, was 16° C. (60.7° F.). The mean temperature of sewage at the Concord Reformatory during the last week in January was 11.1° C. (51.9° F.). The mean temperature of Boston sewage during this month was 6.3° C. (43.3° F.).

SOME FACTS ABOUT THE CHEMICAL TREATMENT OF MYSTIC SEWAGE.

By Wilbur F. Learned, Member of the Boston Society of Civil Engineers.

[Read February 15, 1888.]

Ten years ago the sewage of about a dozen tanneries in Woburn and Winchester drained into the streams that fed the storage reservoir which forms the domestic supply for Charlestown, Somerville, East Boston and Chelsea. Subsequently, the Boston Water Board intercepted this sewage and diverted it to Mystic Lower Lake, the head waters of Mystic River.

The large quantity of organic matter carried down by the sewer soon caused a nuisance in the neighborhood of the outlet to such an extent that the Boston Water Board purchased a level tract of land on the line of the sewer, erected an engine and pump, built tanks and ditches, with a view of abating the nuisance by subsidence. Only a small quantity of solid matter was eliminated by this process, the balance flowing back into the sewer lower down on the line and subsequently into Mystic Lower Lake.

The first set of tanks built for subsiding the sewage was 40 feet in length, 15 feet in width and 3½ feet in depth. The interior construction consisted of partitions extending diagonally from opposite sides toward the centre, leaving a sinuous channel through the centre and giving the appearance much like that of a fish way.

This method of construction was adopted because it was thought that the angles formed by the partitions and sides would cause the agitation of the sewage to cease, and thereby large quantities of solid matter settle at those places; but as a matter of fact the velocity of the sewage in the channel was increased beyond the rate at which the suspended matter would settle, and the sewage in the angles was more or less agitated.

The second set of tanks built 3 or 4 years later than the set already referred to was 50 feet in length, 15 feet in width, and 4½ feet in depth.

Transverse partitions were built in these tanks 9 feet apart, with intervening skimming boards.

The results obtained were an improvement on the first set, but they were far from being satisfactory; and as a sequence all the partitions in both sets were removed, leaving the interior clear of obstructions excepting such posts as were required to support the covering. By this change, the velocity of the sewage in the tanks was reduced to a minimum consistent with the size of the tanks and the quantity of sewage pumped and better results were obtained. Large amounts of money have been expended during the last three or four years to clarify the sewage with a view of obtaining an admissible effluent. Mechanical filtration has been tried without success, and unique devices applied to the tanks in connection with chemical precipitation with only partial success, and at great cost. Subsequently the writer was detailed to experiment and report on a scheme of works for treating the sewage chemically.

Character of the Sewage.—The morning flow is very much diluted with ground water; between 10 and 11 o'clock A. M., and sometimes earlier, the sewage grows heavier until 2 or 3 o'clock P. M., when it reaches its maximum density, having changed in color from dirty water in the morning to brownish black in the afternoon, passing through the various shades of tan to very deep red, and thence to almost black.

The total matter, including dissolved and undissolved matter, in the morning sewage may be stated as containing 112 grains per gallon,* while the maximum amount of matter in the afternoon sewage is 540 grains per gallon.

The suspended matter amounts to 16 grains per gallon in the morning, and 128 grains per gallon in the afternoon, or an average of about 25 per cent of the total matter in the sewage. Occasionally the sewage is slightly alkaline, though generally it is neutral.

The quantity of sewage pumped at these works is about 400,000 gallons in 24 hours.

Precipitation.—The chemical reagent used for precipitation was crude sulphate of alumina of two grades, called S. cake and B. cake. The S. cake contains 3 per cent. free sulphuric acid, 18 per cent. free alumina and 40 per cent. sulphate of alumina. The B. cake contains .005 free sulphuric acid, 18 per cent. free alumina, 44 per cent. sulphate of alumina. The large quantity of free acid in the S. cake soon destroys any iron work with which it may come in contact, and is not therefore as preferable for a precipitant as the B. cake. The amount of precipitant used in the forenoon is always less, and with better results than in the afternoon. For instance,

* The gallon referred to in this paper is the U. S. wine gallon, containing 3.7853 litres. The ton is the Massachusetts ton of 2,000 pounds, or 907.19 kilos.

a precipitant applied to the sewage between 9 and 11 o'clock A. M., at the rate of one-half ton per 1,000,000 gallons will throw down 25 per cent. of the total matter in the sewage, while two tons per 1,000,000 gallons applied to the sewage between 3 and 4 o'clock P. M. will not precipitate more than 30 per cent. of the total matter. I have seen the reagent at the rate of one ton per 1,000,000 thrown down 31 per cent. of the total matter, and with the same sewage a treatment at the rate of two tons per 1,000,000 gallons throw down only 32 per cent. of matter.

Such results seem to show that beyond certain limits the chemicals precipitate a small amount of matter.

The coarse suspended matter is easily precipitated by a moderate amount of the chemical reagent, and some of the finer particles are also thrown down, whereby the effluent is deprived of some of its color, and a corresponding portion of the offensive matter removed; besides this, there is dissolved matter which seemingly undergoes little change in the presence of the chemical reagent.

The quantity of precipitant recommended for the Mystic Sewage is 1.75 tons of crude sulphate of alumina per 1,000,000 gallons, commencing in the morning at seven o'clock with the precipitant at the rate of half a ton per 1,000,000 gallons, and increasing gradually until the amount reaches 3 tons per 1,000,000 between two and four o'clock P. M., then decreasing as the sewage becomes less dense to the rate of half a ton per 1,000,000 at midnight. With this quantity for a precipitant, it is believed that the effluent will be clear, and tolerably free of color, the suspended matter all thrown down, and as much of the dissolved matter as may be consistent with a single reagent.

Should, however, additional purification be required an increased reagent will not give better results, but if the effluent, having all the suspended matter removed, and in a state of comparative purity be run on to land of a gravelly nature, which will act as a chemical filter, a still further state of purity will be obtained.

Velocity of Treated Sewage.—One of the experiments was made with sewage clarified by subsidence, and subsequently treated, thus forming a large quantity of fine flocculent matter which required a long time for precipitation.

The velocity of the treated sewage in the precipitation tanks varied from 0.33 feet per minute to 0.70 feet per minute. In a few instances definite quantities of suspended matter in the effluent were obtained, while in other cases when the velocity was greater no results were obtained. For instance, in one case when the velocity was 0.56 feet per minute, 23 grains per gallon were obtained, and in another when the velocity was 0.37 feet per minute 16 grains per gallon were found, while in cases when the velocity was 0.70 feet per minute no results were obtained.

It should be borne in mind that the precipitation tanks were inadequate for the purpose of precipitation.

If they had been twice as long in order to give the flocculent matter ample time to precipitate, I have no doubt that a velocity of 0.50 feet per minute would have given a very fine effluent free of suspended flocculent matter.

Treatment of Crude Sewage and of Clarified Sewage.—This experi-

ment consisted in treating crude and clarified sewage with equal quantities of precipitant at different hours of the day.

The total average per cent. of matter precipitated from the crude sewage was 29 per cent., and the amount precipitated from the clarified sewage was 30 per cent.

This small difference might have been increased somewhat by a greater number of trials, but the difference will always be small when the amount of re-agent applied to the crude sewage is adequate, because it requires a large quantity of precipitant to throw down the fine particles of matter in the clarified sewage, while the same quantity applied to the crude sewage will give very nearly as good results.

Admitting a slight advantage by treating the clarified sewage when the amount of precipitate alone is considered, the advantages obtained from the crude sewage, such as compact sludge, active precipitation, etc., far exceed that of the former method.

The benefit of having a compact sludge cannot be too highly spoken of, in fact lime is frequently added as a reagent in part for this purpose and is one of the requirements in case the sludge is to be pressed.

Tanks.—When the continuous treatment of sewage is adopted for a scheme of works the precipitation tanks should be made to obtain a depth of 5 feet of treated sewage and of sufficient width to obtain a velocity not exceeding. 50 feet per minute. The nearer absolute stillness is approached the more perfect the precipitation will be.

Obstructions of all kinds, such as posts, should be avoided, and the interior form a clear open channel.

Sludge Disposal.—After the supernatant water has been drained out of the tanks there remains a semi-fluid called sludge, containing in the case of Mystic sludge 85 per cent. of water. The specific gravity of the sludge is 1 017, or about 63.5 pounds per cubic foot. It is estimated that with each million gallions of Mystic sewage there will be 5,000 cubic feet of sludge. The disposal of this sludge has become one of the most important factors in connection with the chemical treatment of sewage.

In England there are seven different methods adopted for disposing of sludge : such as drying in open pits and then given or sold to farmers ; second, run on to land or dug in and deposited ; third, drying and burning in kilns. In short the methods used seem to be those which cause the least trouble and expense.

The most successful method has been by pressing in the "Johnson Filter Press," made especially for that purpose, whereby its bulk is lessened 80 per cent., the fluid portion of the sludge is eliminated, leaving a firm cake, which is sold to farmers at from 5 to 8 shillings per ton.

The plant required for pressing the Mystic sludge consists of an air compressor, an air accumulator, a filter press, a sludge forcing vessel, with the various piping, together with a tip truck and other conveniences for handling the pressed cake. Such a plant would cost for the amount of sludge we will handle $3,000.

Methods of Treating Sewage.—There are two methods adopted in England for treating sewage chemically: the continuous and intermittent. The continuous method consists in treating the sewage with certain

chemicals as a precipitant, and allowing the supernatant water to flow off as fast as may be consistent with the precipitation effected.

For this treatment sufficient tank room must be provided to obtain a very slow velocity through the tanks and to give the treated sewage sufficient time to precipitate. If the sewage is treated after passing through subsiding tanks and has become more or less clarified, the flocculent matter is extremely light and remains suspended for a long time. In which case a second reagent would be advisable to weight the flocculent matter and cause rapid precipitation. Such a reagent would be lime, applied in the form of milk of lime.

When the crude sewage is treated the heavy particles of matter help to weight the finer particles of flocculent matter, and the precipitation becomes more rapid and defecation more complete.

The intermittent method consists in filling a series of tanks with treated sewage and allowing it to stand until the precipitation is complete. The tanks are then emptied and cleaned out in turn ready for fresh supply.

When sewage is treated in this way the full effect of the reagents is obtained, the effluent is clearer and in every way more satisfactory than by the continuous method.

Recommendations.—The following recommendations were made for the treatment of the Mystic sewage.

1st. The intermittent treatment of the sewage.

2d. The construction of four tanks, each capable of holding three hours' pumping.

3d. A sludge well into which the sludge may be drained.

4th. A sludge pump for raising the sludge into flumes that convey it to shallow basins until such time as pressing the sludge may become a necessity.

5th. A branch sewer from the present line of sewer to a pump well on the city's land.

6th. An engine and pump for pumping the sewage into the tanks.

7th. Tanks and machinery to aid the dissolving of the Cr. Sul. Al.

8th. Buildings, including engine house, coal shed, etc., all at an estimated cost of $11,000.

NOTES ON EUROPEAN PRACTICE IN SEWAGE DISPOSAL.

By Charles H. Swan, Member of the Boston Society of Civil Engineers.

[Read February 15, 1888.]

Some interesting statistics relating to sewage disposal by application to land have recently been published by the authorities at Paris and Berlin, which, together with some reported English practice, throw light upon the question as to the quantity of sewage that may be applied to

given areas of land. These statistics have not been reported to the Society, and it may be well to review some of their results in connection with the consideration of sewage disposal at Medfield, Mass.

Paris.—The preliminary experiments with the soil of Gennevilliers, which is an alluvium consisting of sand and fine gravel, led to the conclusion that when used to the depth of two meters it could purify 50,000 cubic meters of sewage per hektar per annum, provided that it were properly drained and that the conditions of frequent and regular intervals of intermittence in the application of the sewage were fulfilled. Subsequent experiment and experience have shown that the best quantity of sewage to use in connection with cultivation is somewhat less than this, and that if cultivation be made subsidiary to purification a very much larger quantity may be applied. The following statistics from the report of M. A. Durand-Claye* give some particulars of this experience.

The gradual increase in the area irrigated and in the amount of sewage distributed from 1872 to 1883 are shown in the following table. This increase still continues and it is expected that sufficient land to purify the entire sewage of Paris will be under irrigation before many years.

PROGRESS OF SEWAGE IRRIGATION AT GENNEVILLIERS.

Date.	Volume of sewage distributed.	Area irrigated.	Volume of sewage per hektar per annum.	Average depth of sewage distributed in the year.	Remarks.
	Cub. meters.	Hektars.	Cu. meters.	Meters.	
1872	1,765,621	51	34.620	3.46	
1873	7,212.928	88	81,965	8.20	
1874	7,078.529	122	58.020	5.80	
1875	5,395,011	199	27 110	2.71	
1876	10,661,224	295	36,140	3.61	
1877	11.756.949	357	32 932	3.29	
1878	10,542.855	379	27,817	2.78	Stoppage from November, 1878, to March, 1879.
1879	10,440,091	399	26,165	2.62	
1880	15,040,645	451	33,349	3.33	
1881	18,666,648	492	37,940	3.79	
1882	18,988,366	544	34,905	3.49	
1883	17.598,416	572	30,766	3.08	
Average			38,477	3.85	
Average for 1875, '76, '77, '80, '81, '82, '83			33,306	3.33	

It will be seen from the above that, after the methods of irrigation had become systematized, the annual volume of sewage distributed varied between 27,000 and 38,000 cubic meters per hektar, and that the working average was about 33,300 cubic meters per hektar per annum.

The degree of uniformity in the monthly distribution of the sewage may be gathered from the following table. Nearly half of the sewage was distributed by gravity, the remainder being pumped.

* Assainissement de la Seine. Paris. 1885.

VOLUME OF SEWAGE DISTRIBUTED MONTHLY ON THE PLAIN OF GENNEVILLIERS DURING THE YEAR 1883.

Month.	Days operated.	Total volume distributed. Cubic meters.	Remarks.
January	5	182,973.60	No pumping; flood in Seine; rainy.
February	19	1,003,326.48	965,000 cu. m. used for irrigation.
March	15	1,136,421.00	Working reduced on account of rain.
April	24	2,139,077.40	Regular working.
May	25	2,155,628.20	" "
June	24	1,877,238.60	" "
July	25	1,827,830.20	" "
August	26	2,221,332.90	" "
September	22	1,456,583.20	" "
October	24	1,006,129.80	" "
November	25	1,573,568.40	" "
December	24	1,018,305.80	Pumps stopped for alterations in conduits.
Average	....	1,466,534.63	

Experiments in flooding and irrigation with large quantities of sewage were regularly made at Gennevilliers for several years. They were commenced during the winter of 1880–81 on a field 1.64 hektars in area. From December 2, 1880, to April 23, 1881 (about five months), 55,117.8 cubic meters of sewage were distributed upon this lot; making 33,608.4 cubic meters per hektar, or a depth of 3.36 meters of sewage. The field was then turned over to the farmers, who raised a fine crop of beets upon it, using during the summer the usual amounts of sewage for irrigation.

Flooding was resumed November 14, 1881, and continued until March 30, 1882 (four and one-half months). The volume of sewage distributed reached 131,213 cubic meters, or 80,008 cubic meters per hektar: the amount of sewage being more than doubled. The experiment was then continued with cultivated plants, which were treated with the greatest possible quantity of sewage. For this purpose a portion of the field, 0.54 hektars, was prepared in furrows 30 cm. and ridges 60 cm. in width. The earth was slightly argillaceous, and the thickness of the soil was about 50 cm. Irrigation was commenced April 25, 1882. The results as regards culture were very satisfactory. During 1883 an amount of sewage equivalent to 113,057 cubic meters per hektar was distributed upon the lot. Irrigation took place every two or three days. There were 158 days of irrigation during 1882.

Allowing for these intervals of rest, the net rate of distribution is equivalent to 48,940 cubic meters per hektar per annum, giving sufficient area to receive a given volume of sewage with intermittent application under these conditions. The frequency of flooding during the experiment from November 14, 1881, to March 30, 1882, is not given; but assuming it to have been about the same, the net rate of distribution to provide for a given volume of sewage becomes 92,348 cubic meters per hektar per annum under this assumption. These numbers may be taken

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THE METHODS AND APPARATUS USED IN THE RECENT TEST OF WATER METERS AT BOSTON.

BY L. FREDERICK RICE, MEMBER OF THE BOSTON SOCIETY OF CIVIL ENGINEERS.

[Read April 18, 1888.]

In March, 1887, L. Frederick Rice, Civil Engineer, Charles Carr, Mechanical Engineer, and Nathaniel M. Lowe, Mechanical Expert, were requested by the Boston Water Board to undertake, in its behalf, the examination of such water meters as might be designated, " making a full test and report upon their merits."

The Water Board gave no instructions as to methods of procedure, and imposed no restrictions whatever ; assuming only that the scheme of work would be carefully considered before adoption, and asking that such scheme, when determined upon, should be submitted to the board for its approval. The desire was expressed that the examination of meters should be " so far public as to leave no room for question."

In compliance with this desire, the work of the Testing Commission has been done in a room open to whoever chose to visit it for the purpose of witnessing the operations. Fortunate in securing skillful assistants, the Commission has been able to dispense with the volunteer aid so kindly proffered at an early stage of its labors.

In the belief that a description of the work done and the methods and apparatus used in these experiments may be of interest to members of this Society and possibly to others, this paper has been prepared.

Before deciding upon the course of action to be adopted in making the desired tests, the Commission carefully considered the functions of a water meter,—the forces by which it is actuated,—the circumstances under which it acts and the various causes modifying its action.

A water meter is an instrument used for measuring water as it passes through a pipe, and recording the quantity measured in such manner as to form the basis of charges for the use of the water.

The *perfect* meter will make an absolutely accurate *measurement*, uninfluenced by variations of pressure, or rate of flow,—guiltless of leakage and undeterred by frictional or other resistance,—and it will honestly and

truly *register* and declare the exact amount of such measurement, regardless of remissness or only partial performance of duty on the part of the measuring apparatus.

It will continue to do this for an indefinite period,—in gritty as well as in clear water,—with the temperature of the air or water below 32° or above 212° Fahr., or at any intermediate point,—located in the attic or in the coal bin,—set level or plumb or in any other position that carelessness or ignorance or malice can devise; and although busy and scheming brains work tirelessly over the problem of how to "beat the meter," it will never be caught napping nor fail in its duty.

We have it from good authority that "the perfect meter has not yet been found."

It might, perhaps, be classed with the philosopher's stone and perpetual motion; tantalizing, but unattainable.

But why seek a standard of measure of greater value than the commodity dealt in? Why should time and money be expended in the search for absolute accuracy in measuring *water*, whose value in this market, sold by meter, is two cents per 100 gallons or 15 cents per 100 cubic feet,—equal to $1.50 per 1,000 cubic feet, or $45 per 30,000 cubic feet, which is an average yearly duty for a ¾-inch meter in this city.

Forty-five dollars per year is 12⅓ cents per day for 617 gallons, or one cent apiece for every person who uses 50 gallons of water daily. If the meter by which this water is to be measured should vary 5 per cent. from perfect accuracy, what would be the yearly cost of the error? $2¼! Fifty-six cents in the quarterly bill!

The Testing Commission endeavored to ascertain wherein the various meters submitted to it failed of perfection, and the degree of such failure; also if such failure was the result of faults of design, or of workmanship, or of material; and also whether any means could be discovered whereby the action of any meter could be improved.

Water is usually distributed through cities and towns by means of a system of pipes, through which it is forced by pumps, or flows by gravitation from some source more or less elevated. If the water in any pipe system is at rest, a gauge applied at any point thereof, would indicate the weight of a column of water whose height equaled the difference in elevation between the gauge and the supply reservoir; or the pressure maintained by the pump. This is designated the "static pressure or head."

If, by drafts upon a pipe system, a movement of the water therein is caused, the velocity of such movement creates certain resistances, by reason of friction of the water upon the interior surface of the pipes, or the obstruction afforded by abrupt changes of direction or of size. In overcoming these resistances, a portion of the static pressure is expended, and water would be delivered upon the premises of a consumer at an effective pressure, which would be the *static pressure* reduced by the sum of such *resistances*, and by the actual withdrawal of a portion of the water for the supply of other consumers.

This may be considered as the initial pressure for any consumer, *not* what is due to the height of the reservoir or pressure at the pump which furnishes the supply.

The usual practice is for individual water takers to bring water from the street main into their premises through a small pipe. In the majority of instances, the inlet or supply pipe for dwelling houses is $\frac{5}{8}$ inch or $\frac{3}{4}$ inch in diameter, and varies in length from perhaps 20 feet to 100 feet, or even more.

At the end of the supply pipe the meter is placed, usually in the cellar or basement of a building, where it will be more or less protected from frost. But when the water is passing through the meter, the velocity of flow through the *supply* pipe creates resistances *therein*, by which the pressure under which the meter operates (as would be indicated by a gauge placed close to its inlet), is not that due to the *elevation of the reservoir*, nor yet the *effective pressure in the main* in front of the premises, but the latter, *reduced* by the resistances encountered in the *supply pipe*.

If the moving parts of a meter are closely fitted, the accuracy of fit causes a resistance to motion—a true friction.

When a valve of a meter is under a heavy pressure its movement develops friction by which resistance is offered to the motion of the piston. If the water passages in a meter are long, or crooked, or of small diameter, or constricted at certain points, or if the ports are small, all these offer resistances to the passage of water through the *meter*. All these meter resistances serve to consume a portion of the pressure at the *inlet* of the meter.

From the outlet of the meter, the house distributing pipe, usually of $\frac{3}{4}$-inch, $\frac{5}{8}$-inch, $\frac{1}{2}$ inch and $\frac{3}{8}$-inch diameter, conveys the water by routes more or less tortuous, to convenient points throughout the house, and it is drawn therefrom through faucets which are situated at various heights above the meter, and which may be opened partially or to their full capacity, as may be desired.

We thus encounter additional resistance in the distributing pipes, and a part of the pressure remaining at the *outlet* of the meter is taken up in overcoming them.

When water finally reaches the faucet, the volume or discharge varies with the amount that the faucet is opened, which is, of course, at the consumer's option.

Or, expressed more concisely, the *initial pressure* at the entrance to the premises of any consumer is reduced by certain resistances met with in the *inlet pipe*, caused by friction upon the interior surface thereof (dependent upon its diameter and length),—changes of direction (dependent upon the number of such changes and their degree and abruptness),—and changes of size, (dependent upon their number and degree).

The initial pressure is further reduced by the resistance offered by the *meter* (dependent upon the intricacy and size of the water passages, and the friction of its moving parts).

The initial pressure is still further reduced by resistances encountered in the *outlet pipe* (dependent upon its size, length, changes of direction and size, etc., and also upon the elevation of the orifice of discharge above the meter).

The quantity of water *obtainable by the consumer* is that which the *effective pressure* (or what is left of the initial pressure after the various

reductions above enumerated) *can force through the orifice of discharge*, and *this* is finally modified by the size and conformation of that orifice, or by the variety of faucet employed and its degree of opening.

Hence it is of vital importance to a *consumer* of water that his piping, meter and fixtures shall be so designed and constructed that the sum of these reductions shall be a minimum.

If the moving parts of a meter fit loosely, there will be more or less leakage of water by the piston or through the valves without communicating motion to the measuring members, and consequently without registration, or with a registration in favor of the consumer.

It is therefore of importance to *water boards*, or any *persons who have water to sell*, that the leakage without registration should be a minimum.

It is of importance to *both buyer and seller* that the details of the action of a meter under any and all circumstances and conditions, shall be *known quantities* and not mere assumptions.

Influenced by the foregoing considerations, the Testing Commission determined to reproduce, as far as possible, the conditions of actual practice, and to test each meter under various initial pressures, combined with such resistances to a free discharge of water as are liable to be encountered,—to note carefully all the data of each experiment and keep a full record of all the results obtained and phenomena observed,—and to make such notes and record a part of the report, in order that the conclusions of the Commission might be verified or disproved by any interested parties.

It was decided that after the accuracy of each meter had been tested, it should be subjected to a trial to determine the effect of continued usage upon the accuracy and also the durability of the meter,—and that examination should finally be made of the interior, to determine its condition and to enable a study to be made of the nature and quality of the materials used in the construction,—the workmanship,—the design, both in general and in detail,—the cost, both of maintenance and originally,—the space occupied,—the weight,—and the facilities for adjustment and repairing; in short to try every meter under all practicable conditions, and make such examination and study as would disclose the cause of, and if possible the remedy for, any erratic action that might be indicated by the record, and show whether an apparent defect was capable of correction or removal either by the use of different material, better workmanship or change of proportions of parts,—or if it was due to the inherent fault or inadequacy of the design of the meter.

Later it was decided to supplement the records and report based thereon, by appending photographs showing the external appearance of each meter tested, and also such portions of the interiors as should seem desirable to exhibit the effects of the experiments.

The meters placed in the hands of the Commission for testing were mostly of 1-inch and $\frac{3}{4}$-inch capacity. In a few instances, where none of the smaller size could be obtained, samples of $\frac{5}{8}$-inch capacity were substituted. The Commission decided to fully try the $\frac{3}{4}$ and $\frac{5}{8}$-inch meters of all the various kinds submitted, before passing to the larger size. Subsequently, in view of the lapse of time occasioned by the multiplicity

of meters to be tested, all trial of the 1-inch meters was omitted. Still it is believed that the experiments made were sufficiently extended, and the study of the construction and action of the various meters sufficiently comprehensive to justify conclusions applicable not only to the particular samples tested, but to the *types* of meters to which the samples belong.

THE TESTING APPARATUS

was devised by the Commission, and was erected in a room constructed in the southerly end of the basement of the Massachusetts Charitable Mechanic Association Building.

The testing-room was about 65 feet long by 24 feet wide, lighted by windows on one side, and having a door at one end, secured by a lock to which only the members of the Testing Commission had keys.

Adjoining the testing-room, and accessible by a passage through it, was a small room, about 12 by 13 feet, used by the Commission as an office, and for the storage of records of the tests, and of meters while not undergoing examination.

During the entire period occupied by the tests and the preparation of the report, no person whatever had access to the testing room, or to any of the meters or testing apparatus, except in the presence of one or more members of the Testing Commission; and none but members or employés of the Commission had any connection with the operation of testing or access to the records thereof.

The testing-room was divided lengthwise by a railing into two equal parts. The testing apparatus was erected in the inner one, and the outer one opened to the public at all times when testing was in progress, —the rail preventing unauthorized access to the meters, or the apparatus, or the records, while enabling visitors to see and hear all of the operations of the tests.

Watchmen were employed, both by day and by night, to see that the premises occupied were not intruded upon,—the watchman's station being outside the testing room, but provided with facilities for observing the entire interior.

A 6-inch cast-iron pipe was laid from the large water-main in the street to the testing-room. This was controlled by a gate at each end, and in the experiments herein described served in place of the street main in actual practice.

To this, within the testing-room, was attached a ⅝-inch lead pipe, about 50 feet long, laid horizontally and controlled by a gate at its junction with the larger pipe.

Another pipe of 1 inch diameter was provided for use when testing meters of that size. It proved useful in experiments where the rate of flow was so slight that the resistance from friction was inappreciable, and could, therefore, be ignored.

The apparatus, therefore, allowed the simultaneous trial of two meters.

The 1-inch and ⅝-inch pipes took the place of the *service* pipes in practice, and to the inner end of either was attached the meter under trial, controlled by gates close to inlet and outlet. The outlet of the meter was connected with several vertical pipes of various lengths, but each governed by a gate at its lower end, so as to be manipulated from the

testing-room. These pipes, of ¾ inch diameter, represented the *distributing pipes* in an ordinary building, and, by means of the gates, water could be discharged at various heights above the meter; while, by the attachment of disks, with orifices of various sizes, to the upper ends of the pipes, the size of the stream discharged was at the option of the experimenter.

The sizes of the orifices used in these experiments were ¾, ½, ¼, .15, .05, .04, .03 and .02 inch.

In this manner it was easy to observe the effect produced upon a meter by drawing water from faucets located in the several stories of a building;—the amount of opening of the faucet being under the control of the operator, who could thus cause water to be discharged at points 7½, 22, 36, and 51 feet above, or at the level of the meter.

The water thus discharged, falling into a funnel-shaped receiver, was conveyed by a pipe back to the testing room, into a tank mounted on a Howe platform scale, where its amount was determined *by weight*. When filled, the tank could be emptied into a drain pipe directly connected with the street sewer.

In order to observe the effect of light initial pressures upon the performance of the meters, as in the case of a building located at an elevation but slightly less than that of the reservoir from which the supply comes, or where the supply is nearly exhausted by other consumers before reaching the one under consideration, tanks were located over the testing-room at elevations of 7, 26, 40, 54 and 84 feet above the meter, with suitable connecting pipes, thus enabling meters to be tried under pressure of the water from either of these tanks in the manner already described.

The pipes from these tanks to the meters were one inch in diameter.

Gauges were placed at the end of the 6-inch pipe, and at the inlet and outlet to the meter.

Plate 1 shows the general arrangement of the testing apparatus as before described, and is self explanatory.

It will be seen that with eight sizes of discharge orifice, and each of these tried at each of five elevations, the apparatus permits the observance of the performance of a meter under forty different conditions; and if all six sources of initial pressure be used, one hundred and eighty-four varieties of condition may be obtained.

Identical results would doubtless be obtained in many instances, and as the record of these, especially if made in the case of 35 meters, would be very bulky, and the time consumed in the experiments very great, it was decided to omit a portion, and the report gives the record of but forty-one varieties of condition.

TEST FOR ACCURACY.

In testing the accuracy of a meter, water was passed through it until a predetermined number of cubic feet had flowed into the measuring tank. The flow was then stopped by closing the gate at the outlet of the meter, and the amount as indicated by the register of the meter compared with that actually received into the tank.

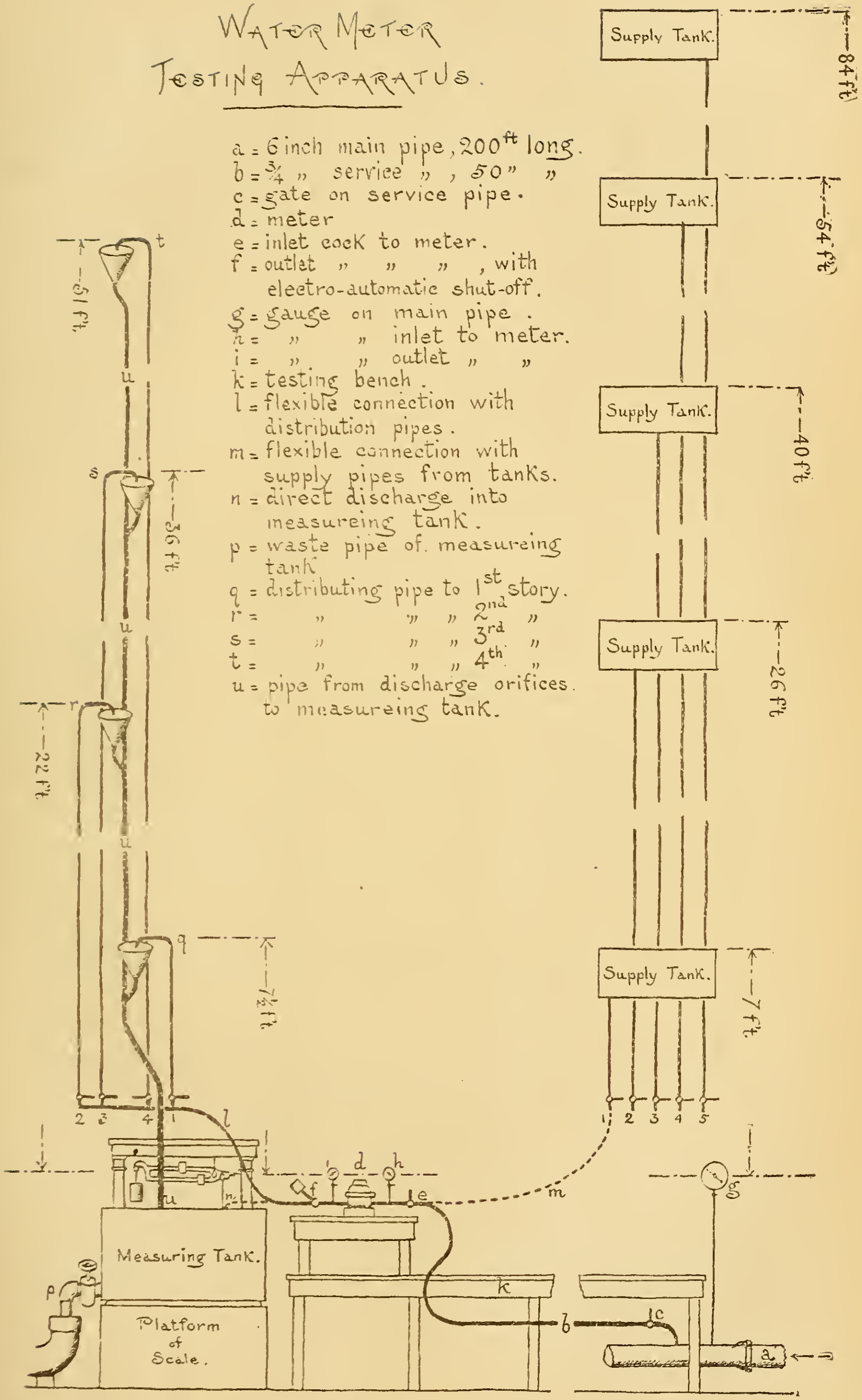
The variation between these is the "error" of the meter.

The register may indicate the passage of *more* water than is received

PLATE I

Water Meter Testing Apparatus.

a = 6 inch main pipe, 200 ft long.
b = ¾ " service " , 50 " "
c = gate on service pipe.
d = meter
e = inlet cock to meter.
f = outlet " " " , with electro-automatic shut-off.
g = gauge on main pipe.
h = " " inlet to meter.
i = " " outlet " "
k = testing bench.
l = flexible connection with distribution pipes.
m = flexible connection with supply pipes from tanks.
n = direct discharge into measureing tank.
p = waste pipe of measureing tank
q = distributing pipe to 1st story.
r = " " " 2nd "
s = " " " 3rd "
t = " " " 4th "
u = pipe from discharge orifices to measureing tank.



into the tank; in which case the meter is said to "over register," or to register "against the consumer." For convenience, in the records of these trials, over-registration is indicated by the sign +.

When the register indicates the passage of *less* water than the measurement shows, the meter "under registers," or "registers in favor of the consumer," and in such cases the sign — is used in the records.

The "error" is given as a percentage of the *actual* flow.

The quantity of water received into the measuring tank being determined by weighing, it is evident that failure to shut off the water exactly simultaneously with the rising of the scale beam, would give an erroneous result, and that such failure would be very liable to occur if the shutting off be done by hand.

It was therefore decided to use an

ELECTRIC AUTOMATIC SHUT-OFF.

The details of this attachment having been perfected, and its construction completed, connection was subsequently made with a stop-clock and an alarm bell.

A photograph of the entire device is appended to the report.

The action of the shut-off is as follows:

At the outlet of the meter under trial is placed a full-way Chapman balance valve, of new and improved pattern, which fully closes with a quarter turn of the handle, actuated by a small lead weight.

When in operation the handle is held down by a detent, connected with the armature of an electro-magnet, the wires from which, passing to the platform scale on which is the measuring tank for the reception of the water from the meter, from a closed circuit.

Upon the reception into the tank of the predetermined quantity of water, the scale beam rises, breaking the circuit,—the handle of the valve is released, and the valve instantaneously closed by the falling weight. Simultaneously, the clock, previously set at zero, and which has been put in motion by the opening of the valve, is stopped,—while the bell calls the attendants to note the duration of the experiment, read the register of the meter and the gauges, and perform any other duties that may be required.

In thus determining the quantity of water by weighing, it was assumed that one cubic foot of water weighed 62½ pounds, and that the scale beam, being weighted for 625 pounds, would indicate when 10 cubic feet had been received into the tank.

This assumption is not absolutely correct, since the weight of a cubic foot of water varies with the temperature, which was therefore observed and recorded, and a correction made when the "error" was calculated.

The temperature of the water during the tests varied from 46 degrees to 76 degrees Fahrenheit, corresponding to a variation in the weight of 10 cubic feet of water of from 622.2 lbs. to 623.75 lbs., and the number of cubic feet, as indicated by the scale, was therefore corrected by multiplying by a factor which varied from 1.002 to 1.0045.

This automatic shut-off proved to be of great value in facilitating the work of testing, since it entirely eliminated the possibility of error by reason of imperfect manipulation of the shut-off or hurried reading or comparison of watches.

Plate 2

1887

…ater Board.

Date of Exp't.	Meter Used.	Sour… of Supp…	…eded C.F. Increase due to Meter %	Flow per minute C. F't.	Flow per minute Decrease due to Meter %	Ratio, Meter to Tank.	Error of Meter + %	Error of Meter − %	Remarks.
May 3	No. 45073	City Pipe		100.21 34.1 2.94		101.2 100.21 1.0099	0.99		Free disch. into Tank
May 3				50.297 21.65 2.32		50.85 50.297 1.011	1.1		1st Back Pres.
May 3				50.394 23.98 2.1		50.9 50.394 1.01	1.		2nd B. Pres.
May 3				50.394 27.87 1.81		51. 50.394 1.012	1.2		3rd B. Pr.
May 3				50.434 34.75 1.45		51. 50.434 1.0112	1.12		4th B. Pr.
May 5			25 4.10 6.1	50.105 21.77 2.3	14 2.44 5.7	50.6 50.105 1.0099	0.99		Free disch. into Tank.
July –			27 4.49 6.	30.338 14.45 2.1	13 2.23 5.8	30.8 30.338 1.0152	1.52		1st Back Pres.
July 7			35 5.01 7.	30.354 16.28 1.86	14 2.00 7.	30.8 30.354 1.0147	1.47		2nd B. Pr.
July 8			31 5.78 5.4	30.351 18.47 1.64	9 1.73 5.2	30.9 30.351 1.0181	1.81		3rd B. Pr.
July 8				30.447 23.27 1.31		30.85 30.447 1.0132	1.32		4th B. Pr.
May 5				50.105 49.95 1.		50.6 50.105 1.0099	0.99		Free disch. into Tank
July 7				30.266 32.73 .92		30.65 30.266 1.0127	1.27		1st Back Pres.

PLATE 2

RECORD OF WATER METER TEST. BOSTON WATER BOARD.

1887

Date of Exp't.	Meter Used.	Source of Supply.	Gauge: On Main.	Gauge: Inlet Work'g.	Gauge: Outlet Work'g.	Gauge: Outlet At Rest.	H'd Lost (friction): Inlet Pipe	H'd Lost (friction): Meter	H'd Lost (friction): Outlet Pipe	H't Outlet above Meter.	Diameter: Inlet Pipe.	Diameter: Outlet Pipe.	Diameter: Orifice.	Duration of Trial: h.	Duration of Trial: m.	Duration of Trial: s.	Meter Reading: Begin.	Meter Reading: End	Meter Reading: Quant.	Temperature of Water.	Tank Measure: By Scale	Tank Measure: Correct'd for Temp.	Time needed to pass 10 C.F.: Actual, Min.	Increase due to Meter %	Flow per minute: C. Ft.	Decrease due to Meter %	Ratio, Meter to Tank.	Error of Meter: + %	Error of Meter: − %	Remarks.
			in.	in.	in.	in.	in.	in.	in.	ft.	in.	in.	in.				C. Ft.	C. Ft.	C. Ft.	°	C. Ft.	C. Ft.								
May 3	No. 45073	City Pipe.	46	13	3	0	33	10	3	0	3/4	3/4	3/4		3 3 3 3 3	47 47 48 48 49	18.	28.10 38.20 48.30 58.45 68.60	101.2	50	100 1.0021	100.21	34.1 100.21 3.4		100.21 34.1 2.94		101.2 100.21 1.0099	0.99		Free disch. into Tank
											do.	do.	do.		34.1 3 3 3 3	46 45 46 49		78.75 88.85 98.95 109.05 119.20												
May 3			46	20	12	1½	26	9	9½	7½	do.	do.	do.		21.65 4 4 4 4 4	24 19 18 19 19	120.	130.25 140.40 150.55 160.70 170.85	50.85	50	50 +12 lbs = 50.192 1.0021	50.297	21.65 50.297 4.3		50.297 21.65 2.32		50.85 50.297 1.011	1.1		1st Back Pres.
May 3			46	25	18	8½	21	7	9½	22	do.	do.	do.		23.98 4 4 4 4 4	51 47 47 47 47	175.	185.30 195.45 205.60 215.70 225.90	50.9	50	50 +18 lbs = 50.259 1.0021	50.394	23.98 50.394 4.76		50.394 23.98 2.1		50.9 50.394 1.01	1.		2nd B. Pres.
May 3			46	30	24½	14	16	5½	10½	35	do.	do.	do.		27.87 5 5 5 5 5	41 32 32 33 34	227.	237.50 247.60 257.80 268 278	51.	50	50 +18 lbs = 50.288 1.0021	50.394	27.87 50.394 5.53		50.394 27.87 1.81		51. 50.394 1.012	1.2		3rd B. P.
May 3			46	36	32	21	10	4	11	51	do.	do.	do.		34.75 6 6 6	57 57 57	281	291.45 301.60 311.80 321.95 332	51.	50	50 +20½ lbs = 50.328 1.0021	50.434	34.75 50.434 6.89		50.434 34.75 1.45		51. 50.434 1.0112	1.12		4th B. P.
May 5			46	21	12½	0	25	8½	12½	0	3/4	3/4	1/2		21.77 4 4 4 4 4	23 20 18 23	333.	343.1 353.2 363.4 [illegible] [illegible]	50.6	[illegible]	50 1.0021	50.105	21.77 50.105 4.35	25 4.10 6.1	50.105 21.77 2.3	14 2.44 5.7	50.6 50.105 1.0099	0.99		Free disch. into Tank
July 7			46	25	17	2½	21	9	14½	7½	do.	do.	do.		4 4 4 14 =14.45	55 44 48 27	475.	[illegible] 495.6 [illegible]	30.8	75	30 +1½ lbs = 30.208 1.0043	30.338	14.45 30.338 4.76	27 2.49 6.	30.338 14.45 2.1	13 2.23 5.8	30.8 30.338 1.0152	1.52		1st Back Pres.
July 7			46	29	23	8½	17	6	14½	22	do.	do.	do.		5 5 5 15 =16.28	27 30 20 17	540	550.00 560.40 570.80	30.8	75	30 +14 lbs = 30.224 1.0043	30.354	16.28 30.354 5.36	35 5.01 7.	30.354 16.28 1.86	14 2.00 7.	30.8 30.354 1.0147	1.47		2nd B. P.
July 8			46	32	29	14	14	3	15	36	do.	do.	do.		6 6 6 18 =18.47	20 8 0 28	553.60	564 574.25 584.50	30.9	74	30 +14 lbs = 30.224 1.0042	30.351	18.47 30.351 6.09	31 5.78 5.4	30.351 18.47 1.64	9 1.73 5.2	30.9 30.351 1.0181	1.81		3rd B. P.
July 8			46	36	34	21	10	2	13	51	do.	do.	do.		7 7 7 21 =23.27	57 39 40 16	715.75	726.25 736.40 746.60	30.85	74	30 +20 lbs = 30.32 1.0042	30.447	23.27 30.447 7.64		30.447 23.27 1.31		30.85 30.447 1.0132	1.32		4th B. P.
5			46	41	35	0	5	3	38	0	3/4	3/4	3/4		49.95 9 10 9 10 10	57 0 59 0 1	386	396.20 406.30 416.50 426.50 436.60	50.6	50	50 1.0021	50.105	49.95 50.105 9.97		50.105 49.95 1.		50.6 50.105 1.0099	0.99		Free disch. into Tank
July 7			41	41	39	2½	0	0	36½	7½	0	do.	do.		10 10 10 32 =32.73	59 53 52 44	505.80	516.10 526.30 536.45	30.65	75	30 +8½ lbs = 30.136 1.0043	30.266	32.73 30.266 10.81		30.266 32.73 .92		30.65 30.266 1.0127	1.27		1st Back Pres.

When trying a meter under a very slow delivery of water, requiring considerable time for a single experiment, the apparatus could be set in operation at the close of a day's work, and then locked up and left to do its duty unattended during the night and tell the whole story in the morning.

When trying a meter under back pressure, or when discharging from an orifice at some elevation above the meter, the pipe to the orifice was filled with water before adjusting the scale, and on the completion of the run, when the tank, having received the weight of water for which it was adjusted, stopped further flow through the meter, the water then remaining in the return pipe was allowed to run into the tank and weighed, and its weight added to that at which the scale had been set.

RECORD OF ACCURACY TESTS. (SEE PLATE 2.)

In the record, as appended to and forming a portion of the report, the following data are given :

The name and number of the meter experimented on.

The source and elevation of the supply of water.

The date of each experiment.

The gauge-reading on main pipe.

The gauge-reading of inlet to meter (working).

The gauge-reading at outlet to meter (working).

The gauge-reading at outlet to meter (at rest).

The difference between the first and second of these gauge-readings represents the frictional resistance of the inlet or service pipe, between the main and the meter.

The difference between the second and third gauge-readings shows the resistance or loss of head due to the meter under trial.

The difference between the third and fourth gauge-readings shows the resistance offered by the house distribution-pipe and discharging-faucet.

The height of outlet above the meter is given, and corresponds to the fourth gauge-reading.

The diameters of the inlet-pipe, outlet-pipe and orifice of discharge are also recorded.

Record is then made of the duration of the trial, showing the hours, minutes and seconds occupied by each run made, and the aggregate—the latter expressed (for convenience of calculation) in minutes and decimals thereof.

Meter-readings, at the beginning and end of each run, and cubic feet of flow indicated for each.

Temperature of the water.

Tank-measure (in cubic feet) as indicated by the scale, and same corrected for temperature.

Ratio between the meter-reading and the corrected tank-measure, from which is deduced the percentage of error of meter, + or −, or over-registration or under-registration.

From the corrected tank-measure and duration of trial are deduced the actual time needed to pass 10 cubic feet;

Actual flow per minute, in cubic feet;

Percentage of increase of time due to use of meter as compared with a

pipe without meter, and percentage of decrease of delivery due to use of meter, showing the amount of reduction of capacity.

These last two items are not recorded unless exceeding 5 per cent.

Upon these record sheets are also noted all details of experiments, such as stoppages, breakages, repairs, repetitions, etc.

TEST FOR DURABILITY.

The object of this test was to determine the effect of continued use upon the accuracy of meters, as ascertained in the series of trials just described, and designated the first test for accuracy.

The 6-inch main, supplying the water for the experiments, was continued into the testing-room, 50 feet beyond the point where the supply-pipes for the trial of single meters branched off.

This main was tapped and 24 one-inch lead branch pipes, spaced at equal distances over the entire length, inserted. Each of these branches was controlled by a stop cock. A long bench was erected over the main pipe, and a drain pipe, with branch openings opposite the stop-cocks, laid beside the main, under the bench; and at the farther end of the testing room, near the measuring tanks, joined the main drain from thence to the street sewer.

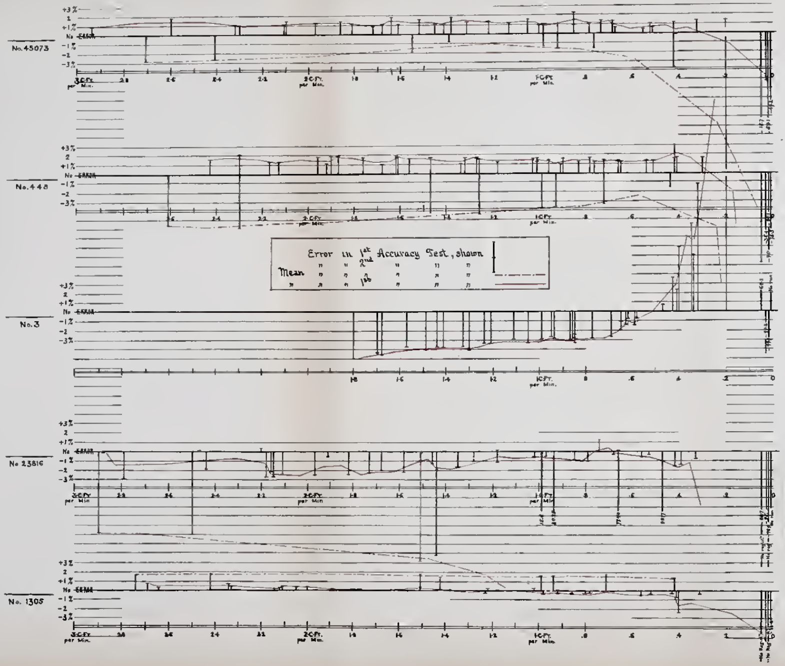
This admitted of a number of meters being placed upon the bench, each connected with a 1-inch supply pipe, and each discharging through a separate 1-inch lead waste pipe with stop cock, into the drain.

All the meters that had passed through the first accuracy test—24 in number—were placed upon the bench and run simultaneously and continuously until their respective registers indicated that about 75,000 cubic feet of water had passed through each. This quantity is equal to about two years' average duty of meters of $\frac{5}{8}$-inch capacity, as shown by the records of the Boston Water Board.

It having been questioned whether the meters located at different points along the main would be subject to the same pressure of water, calculations were made to determine the difference of pressure, if any, between the two extremities and intermediate points. These calculations indicated that the discharge of 99.3 cubic feet of water per minute, which was the rate when all the meters were running, would cause such a velocity of flow in the 6-inch pipe from the street main to the location of the first meter, as would develop a friction considerably reducing the initial or static pressure,—but that the further reduction between the first and last meters would be but $\frac{4}{10}$ pound,—showing that there was no practical difference in the pressures upon the different meters.

To ascertain if observation confirmed the calculation, gauges were placed at each end and in the middle of the bench. These being read, water was then turned on to the first meter, and the gauges again read. The remaining meters were then successively set in motion until all were running; the gauges being read as each was added. The last meter was then shut off, and then the others, successively, until all were again quiescent; still reading the gauges in the same manner. At no time was there any perceptible difference between the three gauges, but the pressure indicated by each steadily diminished as the meters were successively set in motion, and rose again as they were turned off, until on the completion of the experiment the initial pressure of 46 pounds was reached;

PLATE 3.



GRAPHICAL SHOWING OF METER ERROR.

completely confirming the calculations, and showing that the various meters were tried under precisely similar conditions.

The previous trials showed a marked difference in the resistance to flow offered by the various meters, and also in the volume of the discharge in a given time. Those offering the least resistance were the first to reach the conclusion of this trial. As soon as any meter showed by its register that the 75,000 cubic feet of water had passed through it, it was stopped by closing its waste-cock, but the pressure was left upon the meters until all had completed the trial. The time required to pass the 75,000 cubic feet varied from nine to eighteen days.

Ten days after thus shutting off each meter, trial was made to ascertain its relative liability to obstruction by reason of sediment within the meters or by corrosion, or adhesion of parts, or from any other cause, during the period of rest. The waste cock was opened very gradually and without shock, and note made of the degree of opening before water flowed,—the rate of flow before movement of register began,—and the variation from accuracy after starting of register.

The record of the durability trial shows the register reading of each meter three times each day,—the time of completion of trial, or failure, with cause thereof.—and notes of any occurrence of interest, peculiarities or cessation of action, etc., and the causes of same if ascertained.

SECOND TEST FOR ACCURACY.

This trial was made to ascertain the effect of continued usage upon the accuracy of a meter, and was made in a similar manner, and with the same apparatus as the first test, but under a smaller variety of conditions,

The record sheets are in a similar form.

By comparison of the records of the two tests of accuracy, the effect of the wear of the test of durability becomes apparent.

To facilitate such comparison, sheets have been prepared, on which is given a Graphic Representation of Meter Error under all the various conditions of the two tests for accuracy. These show, at a glance, for each meter and each experiment therewith, both before and after the test for durability, the actual delivery of water (as measured in a tank), and the percentage of Error of Registration, either over or under ; also the maximum and minimum percentage of error ; also their mean and the range between them; the average percentage of error, and the effect of wear upon the range and the average ; also the general retarding effect of each meter as compared with a pipe without meter. Plate 3 is a sample sheet of the Graphical Representation of Meter Error, compiled from Plate 2 and other record sheets.

A CONSOLIDATED REPORT

of the test gives, in figures, for all the meters tried, the same information that is conveyed by the Graphic Representation, together with further data relative to the meters tested, such as cost, space occupied, weight, etc.

The flow of water through *pipes without meters,* under all the conditions of these tests, was determined, and is recorded, and has been used in calculating the diminution of flow entailed by the use of the various meters.

SPECIAL EXAMINATION.

After the conclusion of the second accuracy test, the various meters were separately opened, their action studied and their condition examined, after which photographs were made showing the exteriors of the meters, and also all broken or worn portions of the interiors.

In discussing individual meters in the report, the operation of each is fully described.

It was the original intention of the Testing Commission to test the meters under higher pressures after the conclusion of the experiments with the pressure obtained from the city pipes and from reservoirs of low elevation.

For this purpose the connection between the street main and the testing apparatus was to be closed, and a pump applied directly to the 6-inch pipe within the testing-room, by means of which any desired pressure could be obtained, in the same manner as in the Holly or other direct pumping systems.

But the number of meters submitted for testing was so greatly in excess of the anticipations of the Water Board as to so prolong the trials that it became necessary to restrict their scope. It was, therefore, decided not to attempt any tests under the higher pressures.

In addition to these limitations, the tests conducted by the Commission dealt only with the soft, clear water supplied to Boston, and it is not assumed that they will be of use in determining the durability or continued efficiency of meters used with water in which sand or other cutting or scouring material is suspended, or which holds in solution corrosive matter.

But it is believed that the records of these tests give data which will be of value to makers and buyers of meters in considering the utility of any proposed device for measuring water under pressure and recording such measurement.

THE TESTS AND THEIR RECORDS.

In all the operations of testing and recording great care has been observed to insure accuracy.

One or more of the members of the Testing Commission has been present, and taken part in every detail, no matter how trivial.

During the bench trials, the clocks, scales, gauges, meter registers and thermometers were in all instances independently read and separately recorded by two or more observers. These notes have been carefully compared by two persons, and entered upon the record sheets, which form a part of the report. All the calculations based upon these notes have been made by two or three computers working independently of each other, and all the entries upon the record sheets are by the same hand, carefully compared and checked by one or two revisers. Typographical errors being absolutely avoided by photo-lithographing the record sheets, it is believed that the report of the performance of the meters in these tests is substantially correct, and that it shows the action of the meters under circumstances that are identical with those attending their actual use. No two meters in actual service are subjected to precisely the same treatment, and that of any individual meter is constantly changing. No meter, in the trials here reported, has had any usage that it is not liable to encounter at any time.

NOTES ON THE WATER METER SYSTEM OF PROVIDENCE, R. I.—FROM 1872 TO 1887 INCLUSIVE.

BY EDMUND B. WESTON, MEMBER OF THE BOSTON SOCIETY OF CIVIL ENGINEERS.

[Read April 18, 1888.]

I have arranged my subject into the following six divisions, in such a manner as will best answer, in a general way, the most important questions that are frequently asked relative to the water meter system of Providence :

1. The consumption of water in Providence ; the force who read and repair the meters : and general notes and conclusions.
2. Method of testing meters.
3. Manner of setting meters.
4. Different kinds of meters in use.
5. Expense of maintaining meters.
6. Nature of the work charged to the meter maintenance account.

CONSUMPTION OF WATER, ETC., ETC.

During the year 1887 the daily average consumption of water of the city of Providence, and consumers on 15 miles of distribution pipe outside of the city limits, as well as the State institutions in Cranston, was 4,940,000 gallons. This is equivalent to 39 gallons per capita, considering the total population of the city, and the number of consumers supplied in the suburbs.

The average daily consumption per tap has been during the last six years, viz. : 1882, 354 gallons ; 1883, 379 gallons ; 1884, 356 gallons ; 1885, 395 gallons ; 1886, 384 gallons ; and 1887, 376 gallons.

Fifty-eight per cent. of the water services in Providence, had meters on them on December 31, 1887.

Experience has led me to the conclusion that the use of meters prevents an extravagant use of water, while at the same time it does not prevent the quantity being used which is essential for good health and necessary domestic purposes ; as the consumers who pay for the actual quantity of water that they use are much more liable to see that their plumbing and fixtures are kept in good condition, than are those who pay at fixture rates.

I will mention one of the many cases that my attention has been called to, in substantiation of this conclusion, as an illustration. Several years ago, a bill of $117 for one year's consumption of water was presented to a citizen of Providence, and as his bills had not averaged more than $17 previous to that time, he naturally questioned it, and intimated that his meter must be wrong, as he was positive that he had not used anywhere near the amount of water that was specified in the bill. The meter was disconnected and tested, and found to register correctly ; he then had a plumber examine his piping, who reported that it was in good order. The final result was that the Water Board sent two of their own employés to make an investigation, who after spending considerable time discovered a hole in a ¾-inch lead pipe that was laid under a green-house

floor, through which a large quantity of water was flowing, that at once accounted for the unusually large use. Now, in all probability, if this supply had not been metered, as to all outward appearances the plumbing about the premises was in the best condition, this large waste of water might have gone on for years.

If meters had not been used in Providence, there is not any doubt but what the consumption of water since 1871, the time when the Pawtuxet water was first introduced into the city, would have been much larger than it has been ; consequently considerable expense has been saved, with regard to fuel, wear and tear of pumping machinery, and possibly a large outlay for additional pumping plant, etc., that might have been required.

The minimum water-rate in Providence, when meters are set, is $10 per annum. At the present time (December 31, 1887), about thirty-seven per cent. of the consumers who take their supply through meters pay at the minimum rate.

It is generally considered advantageous for consumers, whose bills at the usual fixture rates would exceed $14 or $15 per annum, to have meters set, the $4 or $5 above the minimum amount being allowed for interest on the outlay, and the maintenance of the meters.

The meter system in Providence seems to give satisfaction, both to the city and the consumers who have meters. The meters are the property of the consumers, who are obliged to purchase such as are approved by the Water Department, whose employés set them and make all necessary repairs, etc., at the consumer's expense. It is optional with the consumers whether they will have their services metered or not ; but the Water Board reserve the right to set meters, at their own expense, whenever they deem it advisable ; this is rarely done, however, except in cases where there seems to be a large or extravagant use of water.

The Water Board permanently employs three men who read all the meters quarterly, which takes on the average about five weeks during each quarter ; and do all the necessary water fixture inspection that is required, as well as other work connected with meters, etc., in the office. Probably, if meters were not used, more than three inspectors would be required to examine fixtures, etc.

When meters get out of order, or fail to register altogether, and the consumers have not previously notified the water department of the fact, it is easily detected by these men every quarter, by being obvious at the time the meters are read, or by comparing the amounts registered with the amounts registered during previous quarters, which is always done if there is the slightest question of doubt as to the registration of the meters ; consequently the city sustains very little loss, if any, when meters are found to be out of order at the end of a quarter, as the amount for the quarter is estimated from previous quarterly readings. Meters very rarely fail to register during the first quarter that they are in service, but when they do, as the water bills are payable yearly, with the exception of those of the large consumers, which are collected quarterly, there is generally very little difficulty in estimating the quarterly deficiency.

There is a shop connected with the Water Department, which is fitted up expressly for repairing, testing, and storing meters, etc. Three men,

the total sum of whose salaries is $2,900 per annum, set on the average 490 new meters per year, in addition to making the repairs on all the meters, the average number of which is about 600 per year, as well as disconnecting and resetting them (the original castings, etc., being obtained from the manufacturers). These men also examine all the elevator counters, open and close such service stops as may be required to be attended to when the service pipe clerk is not within call, make out the returns of work done, keep the detail meter repair accounts, and perform other miscellaneous work that may arise.

I have been informed that the only trial it was deemed necessary under the circumstances to give the first meters that were set in Providence was an ordinary tank test, as the Water Commissioners wished to set meters as soon as possible after water was first introduced into the city. The inadequacy of a test of this kind, I think, will be demonstrated by the facts that will be presented as I proceed. It should be remembered, however, that meters which have iron bodies or parts that water can come in contact with, are placed at a great disadvantage on this account alone in Providence, as corrosive action commences to take place in a marked degree upon the iron almost immediately after they are set.

Since the year 1877 there have been tested on the Providence Water-Works, under the direction of the City Engineer, more than twenty different kinds of meters at the request of their inventors or manufacturers, in addition to those meters which are now in actual service in Providence. I shall not mention these meters that have been tried and not adopted, however, as it has not been customary in Providence to disclose the results of their tests, other than to their individual inventors or manufacturers.

If the design of a meter is not obviously impracticable at first sight, it is generally very difficult to form a correct opinion as to its merits until after it has been subjected to one or two years' trial (and it cannot always be done then), for the reason that a meter whose principle and mechanism at a preliminary examination may appear to be commendable, will frequently show in actual service defects where and when they are least expected. The water service pipes in Providence, are sized according to the requirements of the applicants, who, in each instance, fill out and sign an application, which states for what purpose the water is to be used, and the nature and number of the fixtures on the premises to be supplied. The applicants are allowed to have smaller services than their fixtures call for, provided they make the request in writing upon their applications, as well as larger by paying the additional expense of laying, etc.; but in each instance the meter must be the same size as the service pipe (or at least not smaller). This rule, with regard to meters, may appear to be rather arbitrary at first thought, but it works on the whole very well and saves much debate and controversy.

METHOD OF TESTING METERS IN PROVIDENCE.

Before being accepted by the Water Department, the different kind of meters that are under consideration are subjected to several tests. The first test is for accuracy, on streams varying in diameter from $\frac{1}{100}$ to $\frac{1}{2}$ inch, or to the size of the outlet of the meters, the actual amount of water that flows through the meters being weighed.

The second test is for durability, which is accomplished by setting the meter on constant service, in a room prepared for the purpose, in which are laid pipes that lead from the high to the low service, so that a continuous stream of water is obtained without waste, under about 150 feet head. At different periods during this test, if it is thought best, the meters are disconnected and tested again for accuracy on the streams before mentioned. This test for durability is concluded on $\frac{5}{8}$ to 1 inch meters, when from one hundred thousand to four hundred thousand cubic feet of water has passed through each meter. A final test for accuracy is then made, and if the meter registers satisfactorily and an examination shows that they are not badly worn, or have not broken down during the test, they are subjected to the third test, which is made by placing them on regular domestic service ; then at the end of six months or a year or more, they are once more tested for accuracy and once more thoroughly examined, and if the result proves satisfactory they are generally allowed to be set by the Water Department.

After a class of meter has been accepted by the Water Department, each individual meter before being set is tested for accuracy under ordinary pressure on a one-quarter inch stream, and if the error of its registration is not more than two per cent., they are allowed to be set. If the error is more than two per cent. the meters are returned to the manufacturers. A description of the plant used for testing meters (which was first set up during the year 1878), and the general method of testing is as follows : A four-inch pipe, etc., brings the water from a 24-inch main to the bench in the meter room where the meters are tested. A short piece of two-inch flexible pipe is connected to this four-inch pipe. The meter to be tested is placed upon the bench, and the inlet connected to the flexible pipe by a coupling. To the outlet of the meter another short piece of flexible pipe is also connected in the same manner, which terminates in a one-inch brass pipe, which is suspended above the bench on a stanchion, and is so arranged that it can swing in any direction. A one-inch faucet is connected to the outlet end of this brass pipe, which is so arranged, that disks, which have holes of different sizes bored in them, can be fastened into it, so that the size of the stream can be enlarged or reduced at will. At a convenient distance from the test bench an iron tank is located upon an accurate pair of scales. This tank is capable of holding about 600 gallons.

When the meter is connected, and the proper sized disk has been placed in the faucet, on the brass pipe, it is closed, the water is turned on from the four-inch pipe, the faucet swung over the tank and opened, and the water allowed to flow until the hand on the ten-foot dial of the meter registers zero. The faucet is then closed, and the water in the tank weighed. The faucet is then again opened, and after ten cubic feet of water, as registered on the meter dial, has flowed into the tank, it is once more closed, and the water again weighed, and the difference between the weight of water in the tank when the dial registered at zero, and the weight at ten, is referred to a table, on which is shown opposite to figures corresponding to this difference the percentage of error, if any, in the registration of the meter. The test for accuracy is generally concluded, by running a second stream through the meter

while the largest disk is connected ($\frac{1}{2}$ inch for $\frac{5}{8}$ inch), and opening and closing the faucet 100 times.

Pressure gauges are connected to the four-inch and to the one-inch brass pipe, and the tank has an outlet into a sewer, which can be opened or closed by a valve. The tables for determining the error of registration of the meters are based on a temperature of seventy degrees, but if it is considered necessary, the temperature of the water is taken during the test, and if it is more or less than seventy degrees an allowance is made, the table giving a co-efficient for the purpose. A difference of temperature of ten degrees one way or the other, however, will not generally affect the final result more than one-tenth of one per cent.

A new $\frac{5}{8}$-inch meter, if properly constructed, ought not to show an error, when subjected to a tank test for the first time, of more than two per cent., under 70 pounds pressure, on streams of $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$ and $\frac{1}{2}$ inch in diameter, and not more than five per cent. on a $\frac{1}{32}$-inch stream. Under the same pressure it should be able to allow 100,000 cubic feet or more of water to flow through it, at a rate of at least 1,200 cubic feet per twenty-four hours, without showing an increase of error, when again tested for accuracy on the streams before mentioned, from $\frac{1}{16}$ to $\frac{1}{2}$ inch, of more than two per cent. It should also be capable, when new, to work under 70 pounds pressure on ordinary domestic service four years, registering at least 50,000 cubic feet, and not show an increase of error at the end of that time of more than two per cent. on streams from $\frac{1}{16}$ to $\frac{1}{2}$ inch, inclusive.

A good design of meter on ordinary domestic service ought to run on the average at least six years before being repaired, and ought to be serviceable (possibly having to be repaired more or less), for at least ten years.

MANNER OF SETTING METERS IN PROVIDENCE.

Meters are set when possible in cellars, and as near to the stopcock, which is located just inside of the cellar wall, as possible; thereby allowing for the attachment of lateral pipes beyond the meter. Service pipes generally run into dwellings under their cellar floors; in these cases, a small pit is usually dug in which the meter is set, and packed with mineral wool or plasterers' hair as a precaution against freezing. The walls of these pits are generally built of brick, laid in cement, the natural earth being used for their bottoms, in order to let any moisture that may get into them leach away. For the smaller sizes of meters, their average dimensions are about $2\frac{1}{2}$ feet along, $1\frac{1}{2}$ feet wide, and from 1 to $1\frac{1}{2}$ feet deep. When the service pipes enter buildings above their cellar floors, the meters are usually located on shelves fastened to the cellar walls, and boxed up, and packed as before mentioned, unless the cellars are sufficiently heated to prevent the meters from freezing. The pits in the majority of cases are built, and the shelves put up by the plumbers at the expense of the proprietors.

It is always deemed advisable to set meters as low as convenient, in order that the water may be drained from them when it is shut off at the stop-cocks on cold nights by the proprietors (the stop-cocks each having a waste).

Meters are in some cases, it being impossible to avoid it, set outside of

buildings in pits. In these cases the best kinds also have brick walls, the natural earth being used for their bottoms for the reasons before mentioned. In building the walls of these outside pits, a number of bricks are set in each case so as to project into the interior, about half way between the top and bottom, in order to hold up a horizontal wooden partition that is placed upon them; the space between the partition and the cover, which is at the surface of the ground, and is made of wood or iron, being usually filled with hay to prevent the meter from freezing. The average dimensions for the smaller sizes of meters, are about 3 feet square and 5 feet deep. The tops of these pits are arranged so as to prevent surface water from flowing into them. The outside pits, like those of the inside of buildings, are usually constructed by agents of the proprietors at their expense. Proprietors sometimes, however, have their pits constructed of wood in order to save first cost, but this generally results in being more expensive in the end.

If the precautions that I have mentioned, relative to protecting meters, are taken, they are very rarely injured by the cold weather.

DIFFERENT KINDS OF METERS IN USE.

On December 31, 1887, the following water meters were in use in Providence :

Kind.	Size.							Total...
	⅝-in.	¾-in.	1-in.	1½-in.	2-in.	3 in.	4-in.	
Union piston	2,963	580	138	46	6	......	......	3,733
Union rotary	1	......	22	26	3	7	3	62
Crown	3,057	488	123	47	15	3	3	3,736
Fales, Jencks & Sons	15	11	2	......	......	......	......	28
Worthington	61	1	......	......	1	......	1	64
	6,097	1,080	285	119	25	10	7	7,623

The first meters were set in Providence in the year 1872, which was the year following the first introduction of Pawtuxet water into the city.

The Union piston meter was the first kind used. During the first year (1872) 589 of them were set. There were 3,733 in use on December 31, 1887, which is the largest number that ever were in use in Providence. The average number that have been set per year, during the last seven years, is 16. The bodies of these meters, for sizes below 1½ inches, are of bronze, with iron heads ; and for sizes of 1½ inches and upwards they are of iron, brass lined, with iron heads.

The second kind of meter used was the Worthington, which was first set in 1873. During this year 115 of them were set. The largest number that were ever in use in Providence is 168, which was in the year 1876. On December 31, 1887, there were 64 of them in use. The bodies of these meters are of iron.

The third kind of meter used was the Fales, Jencks & Sons', which was first set in 1874. During this year 19 of them were set. The largest number that were ever in use in Providence is 580, which was in the

year 1877. On December 31, 1887, there were 28 of them in service. The bodies of these meters are of bronze.

The fourth kind of meter used was the Union rotary, which was first set in 1877. During this year five of them were set. The largest number that were ever in use in Providence is 63. On December 31, 1887, there were 62 of them in service. The bodies of these meters, for sizes below two inches, are of bronze; and for sizes of two inches and upwards, they are of iron, bronze lined.

The fifth kind of meter used was the Crown, which was first set in 1880. During this year 52 of them were set. The largest number that ever were in use in Providence is 3,736, which was on December 31, 1887. The average number that have been set per year, during the last seven years, is 533. The bodies of these meters, for sizes below three inches, are of bronze: and for sizes of three inches and upwards, they are of iron.

APPROXIMATE COST OF MAINTAINING WATER METERS IN PROVIDENCE.

The detail meter maintenance account was commenced during the year 1878, but has only been worked up to 1886 inclusive, therefore the figures of cost that I shall mention, will not include the cost of maintaining any of the different kinds of meters previous to 1878 (they all having been in service, with the exception of the Crown), or the cost of maintaining them since 1886.

The total cost of maintaining the Crown meters during the entire period that they have been in service in Providence (six years), is, not including eleven meters that have been condemned, $1,462.00, and including the condemned meters, $1,659.00. The average cost per year for each time that a Crown meter was repaired or examined, etc., is, not including the condemned meters, $2.85, and including the condemned meters, $3 17. The total average cost of maintenance, from 1881 to 1886 inclusive, for each Crown meter in use on December 31, 1886, is, not including the condemned meters, 45 cents, and including the condemned meters, 51 cents; also the average cost per year, from 1881 to 1886 inclusive, for maintaining each Crown meter in use during each year, is, not including the condemned meters, 23 cents, and including the condemned meters, 26 cents. All of the other kinds of meters were in service in Providence, before the detail maintenance account was commenced, and with the exception of the Union piston meters, and the Union rotary meters (which are nearly all large sized meters and are generally set on elevator or motor supplies), are gradually being taken out of service, condemned, and replaced by other kinds of meters, I will only mention individually, in addition to the Crown, the cost of maintaining the Union piston meters.

The total cost of maintaining the Union piston meters in Providence, from 1878 to 1886 inclusive, is, not including 121 meters that have been condemned, $13,685, and including the condemned meters, $16,671. The average cost per year, for each time that a Union piston meter was repaired or examined, etc., is, not including the condemned meters, $3.10, and including the condemned meters, $3.67. The total average cost of maintenance from 1878 to 1886 inclusive, for each Union piston meter in use on December 31, 1886, is, not including the condemned meters, $3.74, and including the condemned meters, $4.75; also the average cost per year, from 1878 to 1886 inclusive, for maintaining each Union piston

piston meter in use during each year, is, not including the condemned meters, 44 cents and including the condemned meters, 53 cents.

In Providence the manufacturers of the Crown meters bear the expense of all the repairs, due to defects in the meters, that are made on them during the first three years that they are in service; and the manufacturers of the Union piston meters bear the expense of all the repairs, due to defects in the meters, that are made on them during the first year that they are in service. This expense was included in working up the preceding figures relating to the cost of maintaining the Crown and Union piston meters, as I wished to ascertain the entire cost of maintenance, without reference as to who bore the expense.

Included in the preceding figures, relating to the cost of maintaining the Crown and Union piston meters, are several charges which are not due to any fault of the meters themselves, the most important of which are those of repairing frozen meters. I have not as yet had time to investigate this side of the question as thoroughly as I would wish ; but I shall not be very far out of the way in saying that the total cost of maintaining the Crown meters, not including the condemned and frozen meters, is $806, or 45 per cent. less than the preceding figures relating to the Crown meters, and including the condemned and not the frozen meters, $1,003, or 40 per cent. less ; and the average cost per year for each time a Crown meter was repaired or examined, etc., not including the condemned and frozen meters, is $1.95, or 32 per cent. less, and including the condemned and not the frozen meters, $2.36, or 26 per cent. less. Under the same conditions the total cost of maintaining the Union piston meters not including the condemned and frozen meters, is $12,398, or nine per cent. less than the preceding figures relating to the Union piston meters, and including the condemned and not the frozen meters, $15,404, or eight per cent. less ; and the average cost per year for each time that a Union piston meter was repaired or examined, etc., not including the condemned and frozen meters, is $2.89, or seven per cent. less, and including the condemned and not the frozen meters, $3.51, or five per cent. less.

A GENERAL CLASSIFICATION OF THE NATURE OF THE WORK CHARGED, FROM 1881 TO 1886 INCLUSIVE, TO THE MAINTENANCE ACCOUNT OF THE DIFFERENT KINDS OF WATER METERS USED IN PROVIDENCE.

For the Union Piston Meters.

	Times.		Times.
Yokes worn	54	Dials clouded	194
Shafts worn	705	Glasses broken	88
Cranks worn	8	Covers broken	9
Piston connections sprung	6	Clock work out of order	50
Shafts broken	13	Worn	431
Shafts bent	6	Rusted at heads	551
Cylinders indented	17	Frozen	193
Piston worn	19	Surface water	88
Piston sprung	12	Leaked at stuffing box	123
Piston bound	14	Leaked at heads	22
Stem gears worn	32	Nuts loose	200
Valves worn	10	Packings blown out	19
Did not register	11	Solder in meters	6
Examined	262	Cylinders burst	7
Miscellaneous	99	Condemned	69

For the Worthington Piston Meters.

	Times.		Times.
Spindles bound	156	Miscellaneous	39
Leaked at spindle	17	Condemned	72
Rusted	69		

For the Fales, Jencks & Sons' Blade Meters.

	Times.		Times.
Blades bound, etc	988	Worked hard	23
Frozen	76	Rings blown off	10
Leaked at stuffing-boxes	45	Did not register	14
Leaked at rings	9	Rust in meter	13
Clock work broken off	10	Miscellaneous	36
Clock work out of order	19	Condemned	441

For the Union Rotary Piston Meters.

	Times		Times.
Rusty	9	Leaked at stuffing-boxes	7
Pistons	10	Glasses broken	5
Shafts worn	8	Floats bottomed	19
Worn	9	Dials clouded	5
Caps worn	6	Miscellaneous	21
Obstructions in meters	6	Condemned	3
Frozen	6		

For the Crown Rotary Piston Meters.

Which is the total, from the year that they were first introduced in Providence. The other meters, it must be remembered, had been repaired more or less, before the detail repair account was commenced.

	Times.		Times.
Frozen	98	Clockwork out of order	27
Hot water	48	Dials clouded	5
Leaked at stuffing-boxes	59	Leaked at couplings	8
Piston spindles broken	45	Pistons broken	5
Packings blown out	18	Examined	66
Glasses broken	19	Miscellaneous	69
Obstructions in meters	36	Condemned	11
Rust in meters	14		

The total cost, from 1878 to 1886 inclusive, of maintaining all the different kinds of meters in use in Providence, is, not including 678 meters that have been condemned, $19,910, and including the condemned meters, $38,184. The total average cost of maintenance, from 1878 to 1886, inclusive, for each meter in use on December 31, 1886, is, not including the condemned meters, $2.79, and including the condemned meters, $5.35; also, the average cost per year, from 1878 to 1886 inclusive, for maintaining each meter in use during each year, is, not including the condemned meters, 44 cents, and including the condemned meters, 78 cents.

The terms used in the preceding classification, are those used by the men who repaired or examined the meters. I have not attempted to correct them, technically or otherwise.

The items specified by the word miscellaneous, are the class that has not occurred individually five times.

THE PRALL SYSTEM OF DISTRIBUTING HEAT AND POWER FROM CENTRAL STATIONS.

By E. D. Meier, Member Engineers' Club of St. Louis.

[Read May 2, 1888.]

Heat is the condition of all life and the foundation of all power. These facts, so clear to the modern engineer, were foreshadowed by the imaginative Greek who invented the myth of Prometheus, that demigod who snatched from Olympus the living fire which was to enable mortal man to become even as the gods themselves. They were the living truths underlying the fire or sun worship of the Parsee race. In this

sense the mechanical engineer may lay claim to a spiritual ancestry far antedating that of the proudest monarchs of the world.

We now know, what they darkly felt or imagined, that the sun is, for us at least, the source of all power and the upholder of all life. Not only does he lift up millions upon millions of foot-pounds of energy in the vapors which he raises from the sea to feed the water powers of the highlands of our continents, not only does he direct and limit the forces of the winds which still continue to do so much of the world's work; but we know that ages ago with beneficent profusion he stored up for us in the coal measures a limitless supply of force, which we can at will liberate from its long imprisonment and turn to our uses. To-day this antediluvian supply determines by its location and condition where the great hives of modern industry shall be planted. But we must modestly confess that we have not yet learned the A B C of economy in the use of this great gift of nature.

If we will put aside those facts and statements based on the best foreign or the best Eastern coals, and confine ourselves to what lies nearest at hand, which is, of course, the problem for us to solve, we find that:

The best possibilities in our average Illinois coal are the liberation of 11,580 heat units from each pound of this fuel consumed. We have theoretically necessary to give us one horse-power per hour 2,565 heat units. Hence one pound of coal burned per hour should give us 4½ horse-power. But we find that our best steam plants, with high pressure engines of the Corliss or an equally economical type, coupled with the best boilers, require three pounds of coal for each horse-power per hour, which is equal to 13½ times as much fuel as it should take theoretically. And this may be placed as for our locality the best present possibility in practice, which can only be reached in large plants, where both the engineer in charge and the firemen at the boilers are considered, taught, and paid as skilled laborers. In most smaller plants where a cheap boiler and cheap engine, pipes poorly covered (or perhaps not covered at all) are handled by underpaid, and consequently unskillful or careless men, from eight to eleven pounds of coal are used per horse-power per hour, which is from 36 to 50 times as much as theoretically necessary, and from 2⅔ to 3⅔ times as much coal as would be used in plants attaining the practical minimum above stated. But I know of cases where the record shows a consumption of 80 times the theoretical quantity, or six times the quantity of fuel for each hour's run that is actually used in the best class of plants before described. Now since the best types of engines and the best types of boilers, the best types of heaters, and all other appliances cost very much more per unit of power for small plants than for large ones, and since the higher grade of intelligence, in what is one of the highest and most useful branches of manual skill, can only be had for proportionately good pay, it is clear that we cannot expect to develop anything like the economy aforesaid in small plants scattered all over the city, under sidewalks or up in garrets, etc. Furthermore, the principal danger about the steam plants will always be located in the boiler room. And you cannot but regard it as a great mistake that the good old rule which insisted on placing the boil-

ers entirely outside of factory buildings is utterly disregarded in the smaller and larger plants scattered about populous cities for such purposes as heating, cooking, running elevators, printing presses, sewing machines, electric light plants, etc. A recent report of a board of experts consisting of Profs. R. W. Raymond and Geo. Plimpton, and Mr. C. C. Martin, C. E., refers to this matter as "the growing danger from steam boilers of all sizes distributed in buildings and under sidewalks, and employed in running elevators, dynamos, printing presses, and other machinery. That destructive accidents from this source have hitherto been few is a gratifying circumstance, which must not be permitted to obscure the fact that the danger is constantly increasing with the number of such boilers and with the growing age of those now in use."

Add to this the danger from conflagrations in the overheating of flues entirely inadequate to the work they are called upon to perform; the cost of bringing in coal and carrying out ashes to and from places narrow, dark and scarcely accessible, and the dirt accompanying this transportation. Consider further the smoke and soot, and worse still the invisible gases of combustion, which vitiate the air in rooms in which numbers of men, women and children spend their days in labor, and even perceptibly affect the very atmosphere of the streets, and the fact that all these evils grow with the greater concentration of the best part of our population, *i. e.*, the workers, in districts where the height of buildings constantly increases with unchanged width of streets. We have then reasons enough to account for the many attempts which have been made to concentrate the work of producing this heat-energy in certain central stations, near the fuel supply and more or less remote from the localities where it is to be utilized. Pittsburgh's phenomenal and almost magical transformation by its natural gas supply, has necessarily directed our thoughts to the substitution of a gaseous fuel, flowing in constant supply in underground mains under the streets, and distributed right and left alike to manufactories, office buildings and private residences. There are hundreds of gas producers either seeking for recognition or actively at work on this problem. At the outset it behooves the engineer to inquire into the possible or probable limitations of such a system. The example of the gas light companies teaches us that even with low pressure in the mains, leaks are constant and unavoidable. Increase enormously the quantity of gas required, and we must either use very much larger, or a greater number of pipes, or resort to pipes as strong and joints as carefully and securely made as those which gave the Philadelphia Co. in Pittsburgh its great success. Pittsburgh has not yet eliminated natural gas explosions from its weekly history, although they may no longer create a sensation. But the necessity of the expensive, because thorough, methods of the company aforesaid is acknowledged, and to such methods alone can we look for the prevention of gas explosions. Whether the minor leakage along such lines causing impregnation of the soil, corrosion of the lead water pipes, or of the electric insulators, and possible vitiation of the atmosphere sufficient to intensify if not to create epidemics, may not in course of time show even natural gas to be a not unmixed blessing, we cannot here discuss. The precautions,

dimensions and mechanical contrivances found necessary in Pittsburgh's excellent system will no doubt limit the supplying of manufactured fuel gas to certain districts where the quantities are great and the necessities imperative. Furthermore the fuel gas solves but the first half of the problem in furnishing the fuel in the exact condition in which it can best be burned, while the great multitude of small consumers, who will always create the bulk of the demand, require not this raw material but the manufactured product, *i. e.*, the heat energy itself ready at hand in the smallest sub-division. I am, therefore, convinced that fuel gas when its use becomes general will be distributed direct to certain larger plants where the best appliances and the most skillful handling can be had, and that from such the live heat energy will be portioned out to the army of small consumers.

Large central steam plants have been and are being successfully operated in favorable localities, and where they have been originally designed and built with great scientific knowledge and practical skill. Where these have been wanting they have failed, always will fail and ought to fail. They naturally require very large pipes and joints difficult to make and more difficult to keep tight, because not constantly accessible. Steam being very elastic cannot be pumped or forced by mechanical means, but finds its own velocity at the expense of loss of pressure, loss of temperature and continuous condensation. From these result the always annoying and sometimes dangerous "water hammers" and wet steam and other kindred evils for the consumer. And these evils increase proportionately the larger the demand for heat or power made upon the pipes, so that invariably when most needed the service is least good.

Hot water, i. e., very hot water, a great deal hotter than any one has ever *seen* it, next offers its solution. Water having the greatest capacity for heat of any known substance (except certain chemical solutions valueless for practical purposes) has been chosen as the measure of specific heat for all substances. A cubic foot of water at 400 deg. F. carries 22,000 heat units, while a cubic foot of steam at the same temperature carries but 682 heat units, *i. e.*, but 1-32d as much. There is no difficulty in forcing water. under any pressure, through pipes at a speed of ten feet per second. Steam can be made to travel much faster, but many practical considerations limit the safe speed in long pipes to about 60 feet per second. While no hydraulic engineer would hesitate at pressures in water from 400 to even 1,000 pounds per square inch, I doubt if any steam engineer would have the hardihood to propose supplying a large and complicated net-work of underground pipes with steam at much more than at 100 pounds pressure. If we assume 125 pounds gauge pressure (equal to 140 pounds absolute) as the present practical limit. we find that our cubic foot of steam carries 376 heat units, or about 1-60th of the quantity held by one cubic foot of water at 400 degrees F. From practical considerations such as these we may then deduce the statement that a steam plant should have five to ten times the pipe area of a hot-water plant, *i. e.*, its pipes must have from 2¼ to 3½ times the diameter of those of the hot-water system.

While there have been earlier systems of hot water supply, limited in

extent, and some are to this day running with eminent success, the Prall system for supplying heat and power from central stations, is, I believe, the first which has been put successfully into service on a large or metropolitan scale. A short description of the system will show where it differs from its precursors in methods and appliances.

We have first a central station with its batteries of boilers of a safety pattern, *i. e.*, constructed with comparatively small shells and small tubes, all with internal pressure, so that all parts of the elastic steel structure shall be in tension, and with a circulation so positive that differences of expansion, which would be caused by differences of temperature, are eliminated. Next, in addition to the ordinary feed pump, we have a pump or a number of pumps for taking the water from the boilers and driving it through a series of street mains carefully wrapped with non-conductors, and placed in an accessible conduit of brick or wood, each of which mains constitutes a complete loop, so that its further end returns directly to the boilers, the egress and ingress nozzles being so placed as to increase the natural circulation of the water in the boiler. At distances prescribed by street and alley crossings, but limited to lengths of 100 to 150 feet are placed expansion joints, being simply castings, bolted to one end of each section, and to a solid block of foundation, into the further end of which enters through proper stuffing-boxes a phosphor-bronze sleeve which forms the initial end of the next section of pipe. These castings are so arranged as to take at the same time the expansion joints of a return main to be afterwards described, and the cross connections for the intersecting street or alley. Close to them are also placed stop valves to make it possible to cut out one section at a time for repairs while temporarily supplying the district beyond through the next street main, which thus for the time becomes a by-pass pipe.

In each section is also placed a check valve, being a simple spherical enlargement of the pipe, in which a heavy metal ball is so located that it can roll into and close the conical mouth of the pipe to either side as soon as the fixed maximum speed of the water is exceeded. In case of accident, therefore, or of malicious injury, the two nearest check valves would shut off the injured section, so that the leakage would simply have the effect of flooding the conduit to a depth of a few inches with water, while the steam formed therefrom would be rapidly dissipated at a very low pressure. An explosion cannot occur here, since, in the opinion of the best experts, a good-sized rupture even of the shell of a boiler, when entirely under the water line, will rarely cause an explosion, since water alone, no matter at what pressure, will not readily attain a dangerous velocity. In the case of our pipe we have cooling influences at hand to reduce the effect of such ruptures, while, in the case of a boiler, additional furnace heat is constantly adding to the pent-up energy. At intervals of about 20 feet a coupling is placed, which at the same time is utilized for supplying service boxes placed at the sidewalk. These couplings have special threads, having the peculiarity that the base of the thread is conical, *i. e.*, runs out, while the crown of the thread is sharp and cylindrical. By this means the weakening of the pipe is diffused over a considerable length, so that experiments have shown it possible to preserve 97 per cent. of the full strength of the pipe.

Furthermore, this form of thread can be so forced into the coupling as to actually bed the metal of the pipe into it and make an absolutely tight joint, even under the test pressure of 1,500 pounds.

All pipes before being laid are tested to 4,000 pounds pressure; a certain percentage of them, however, are tested to rupture, which generally requires over 12,000 pounds. Each section when laid is again tested to 1,500 pounds, and made tight under this pressure, and finally the whole main is tested to 1,500 pounds per square inch. The entire supply pipe or force main rests on rollers supported on cast-iron brackets about fifteen feet apart. The same bracket holds under its arched base a return pipe of double the diameter of the pressure main, which rests and rolls on a small iron trolly supported on the base plate, the whole being bolted down to a brick pier. This larger return pipe also forms a complete loop under the pressure main; it has similar joints, couplings and expansion sleeves. The whole pipe system, after being tested, is wrapped with an asbestos covering, over which is secured a layer of asbestos cloth painted with water-proof paint. Over this, with a liberal air space between, is placed a brick arch, outside of same another air space, and still another brick arch, the outside of which is covered with some water-proof cement. The Board of Experts before referred to found the loss in temperature of a four-inch hot-water main in Boston to be only four degrees for a length of nearly two miles, and that at a minimum speed of the circulating current of one and a half feet per second. The claim of the Boston Company that their entire loss by radiation will not be more than two and a half per cent. on the average therefore seems well founded.

From each coupling in the hot main a one-inch pipe runs to the service box located at or under the sidewalk, where by means of a tee it branches into three openings, each closed by an asbestos-packed cock. From this point to the inside of the house wall generally, a distance of less that ten feet, a small copper supply pipe runs to the converter, copper being used to enable the steam fitters to run their pipe in any direction around obstructions to the point where the converter is most conveniently located. These pipes run generally from one-eighth to three-eighth inches in diameter, one inch being a maximum. The converter is simply a steel vessel taking the place, in the house, of the steam dome, which is not required on the boilers at the station. The small copper service pipe terminates in a pressure-reducing valve screwed by a short nipple against the converter. These valves are controlled very nicely and accurately by electricity. To the top of the converter the steam pipe either for power or for the ordinary steam system of the house is attached, being of the same dimensions as if attached to a local boiler. Each converter is further supplied with a steam gauge to show the pressure at which it is set; at its bottom it connects through a return pipe into the service box, and from that back into the return main. As a further precaution a pop safety valve is placed in a horizontal position at the bottom of the converter, so that in case of excess of pressure by a failure of the reducing valve to do its work, the water can be discharged through the safety valve into the return system. Where ordinary steam-heating plants exist in a house the steam pipe from the top of the converter is simply connected with the same, the connection with the boiler

being broken. The same applies to the connection of the system to an existing power plant. Where furnaces or indirect heating or ventilating systems are to be replaced a coil of pipes is substituted, either directly from the main with hot water or from the converter with steam. For cooking a range is used in which a net-work of these small hot-water pipes is placed so as to give a constant temperature, sufficient for cooking, baking, etc.; in fact, every operation except broiling, and ranging from 350 to 400 degrees F. It will be seen that by using two converters we may first extract from the hot water sufficient steam at 70 or 80 pounds pressure to drive the power plant of a building, and from this pass the water into a second converter to furnish a further supply of steam at a very low pressure, which may be supplemented by the exhaust from the engines to heat the entire building in the coldest weather. I have above considered only the difference in economy between large, well regulated power plants, and small, cheap, local ones. When we come to compare the cost of this system with the cost of fuel for domestic heating and cooking purposes we find that only 10 to 15 per cent. of the heat in the coal is there in practice utilized, as against from 50 to 75 per cent. in steam boiler plants. The Boston Heating Company, which has had this system in use on a large scale during the past winter estimates for ordinary city houses about $1\frac{1}{10}$ heat unit per cubic foot per hour. I have found in good examples of steam heating in this city a consumption somewhat larger, but as in my case the buildings were used for offices, where on account of almost constant opening of doors a larger loss of heat may be expected. I believe it to be perfectly safe to figure on 2 heat units per cubic foot per hour as a maximum. Of course, this will be much modified by the circumstances of exposure.

If we consider 5 pounds gauge pressure as ample for steam heating on the average, we find that at this pressure our hot water at 400 degrees F. will give us nearly 20 per cent. of its weight as available steam and still have a large quantity of heat left in the other 80 per cent. for indirect radiation, or for heating water for baths, etc. At the pressure mostly used for pumps, elevators and small engines about city buildings, say, not exceeding 70 pounds, the same water will return us about 10 per cent. of its weight as available steam, the other 90 per cent. being further available for the other purposes above mentioned, and, of course, the exhaust from these engines can be further directly applied for warming, ventilation, etc. Practically then a 4-inch pipe would, at a speed not exceeding 10 feet per second, be able to completely supply 50 average stores of 25 feet frontage, 120 feet depth and three stories of each being heated and each supplied with its own elevator. Since, however, a plant of this kind will always run during the whole 24 hours, and, therefore, the brunt of the fight against cold can be borne by the system during the early morning hours before there is any demand for power, we may reasonably expect to get a result fully 20 per cent. better.

Whenever the plants of heating companies under this Prall system become of sufficient size, a great deal of the water from the return becomes available for condensation at the station, thus reducing the cost of running its own pumps, electric light and fan engines. The water after all its service has been performed, is thoroughly filtered to remove

any grease, grit or dirt it may have picked up in its wanderings, and is then pumped back into the boilers by ordinary feed pumps, passing on through the same pipe and mixing with the water which comes back from the return end of the pressure main. The system has been not inaptly compared by its promoters to the Gulf Stream, which furnishes an example of the great distance to which water can carry heat, thus making the tropical sun of the West Indies exert a genial effect on what would otherwise be the glacial coasts of Northern Europe. When a new main is first put into service, the hot water is pumped through it at a low speed, and this is continued until the conduit and its surroundings are well dried out, and the minimum speed for that main is then fixed by the rule that the last consumer, *i. e.*, the one nearest the station on the return end of the loop, is entitled to a temperature of not less than 390 degrees. When the house connections are afterwards all made, while the inflow of the pipes will be at a much greater rate of speed, as long as the return end of the loop maintains this minimum speed the last consumer will be practically as well served as the first. Each station contains apparatus for measuring and recording temperatures and pressures of the boilers, of the outgoing and incoming main, and of the return main. An inspection of the Boston plant in its every day working must convince the most skeptical that the solution of the heat and power problem of modern municipalities has been found, and that a continuance of the same methods of thoroughness will advance this solution still further, and probably soon fix the limits of such systems in all directions as concisely as they have been fixed for our ordinary gas and water supply. While the great first cost of such a system will in every city limit its first application to the most thickly built-up portion, and therefore to the business section, its advantages will there become so palpably manifest that such central stations will gradually be found supplying the best settled residence districts also, especially since the margin between domestic economy in fuel and that possible in such a station is much greater than that existing between it and ordinary isolated steam power plants in the business section.

One fact bears strong testimony alike to the correctness of the system and the thoroughness with which the chief engineer of the company, Mr. Arthur V. Abbot, C. E., has done his work in every detail of design and execution. As soon as the first two boilers (Heine patent) were put in position a steady circulation of warm water was forced throughout the entire main, the temperature gradually increased up to 380 degrees, and next a solution of potash was pumped into the main and circulated for several days to remove all traces of grease and red-lead. Then this hot potash water was replaced by fresh warm water until no more signs of contamination existed. During about ten days consumed in this manner, the whole of the line was carefully watched as to leakages and the working of the expansion joints. Thereupon house connections were immediately made and heat and power supplied during the entire winter, without an hour's interruption from any cause whatever, during which time eight more boilers were successively placed in service. Parties using the steam testify to its being unusually dry. When snow was on the ground there was no sign of its melting faster over the conduit

than in other parts of the street, except at the man-holes, which are simply covered with two iron plates with an air space between them.

THE WATERWAY BETWEEN LAKE MICHIGAN AND THE MISSISSIPPI BY WAY OF THE ILLINOIS RIVER.

By Robt. E. McMath, Member of the Engineers' Club of St. Louis.

[Read May 30, 1888.]

Many and various have been the projects for a waterway between the Great Lakes and the river system flowing into the Gulf of Mexico. At a comparatively early date in the history of what was once known as the West, canals were constructed from Lake Erie at Erie, Pa., to the Ohio River at Beaver, Pa.; from Lake Erie at Cleveland, O., to the Ohio River at Marietta, by way of the Muskingum River, and to the Ohio at Portsmouth, at the mouth of the Scioto River ; from Lake Erie at Toledo, O., to the Ohio at Evansville, Ind. ; from Lake Michigan at Chicago, to the Illinois River at Lasalle, and from Lake Michigan at Green Bay, to the Wisconsin River at Portage, Wis.

All of these canals were, in a sense, the offspring of the Erie Canal of New York, and, considering the time and circumstances of their construction, were creditable exhibitions of enterprise on the part of the builders. That their usefulness has mostly passed is no discredit to those who planned and built them. They served their purpose well while the conditions in view at the time of construction lasted. The conditions existing in 1888 require something different.

Of the several routes by which a waterway connection between lake and river systems is possible, that by way of the Illinois is, beyond comparison, the most favorable, in ease of execution, availability for economical use, and especially as inviting a liberal scale of dimensions. It is the only one by which a connection available for naval use is practicable, and, according to the commercial requirements of to-day, the only one whose value as a route for actual transportation is worthy of serious consideration. The other routes have passed out of mind, and most of them from the maps, but this has never been lost sight of, and now engages more attention than ever before.

By the favor of the Citizens' Association, of Chicago, copies of a brief, prepared by L. E. Cooley, C. E., entitled "Lakes and Gulf Waterway," were recently distributed to the club. That brief covers the history of the existing canal, and of the several projects that have received official consideration, so fully that I have no occasion to go over any of that ground.

Personally I was engaged upon the surveys made of the Illinois River in 1866 and 1867, and I was in local charge of the work done by the United States on that river from 1869 to 1872.

The reports made after the surveys of 1866 and 1867 both favored the canalization of the Illinois River, but the plan presented was not formally approved by Congress or an appropriation made to begin the work. The

chief argument then advanced for the improvement was military and naval necessity, an argument which derived most of its force from some of the incidents of the then recent war of rebellion. As time passed, the force of this argument was lost, and the great cost of the canal part of the project frightened Congress. The State of Illinois began the work by authorizing the construction of a lock and dam at Henry, in 1869, devoting thereto the net revenues of the Illinois and Michigan Canal. The appropriations for river and harbor work that year were made in a lump sum, to be expended at the discretion of the Secretary of War. Out of that appropriation an allotment of $85,000 was made for work on the Illinois River. I was put in local charge of the work by Gen. J. H. Wilson, with instructions to expend the allotment in dredging the channel of the Illinois River below Henry, so as to prepare a bottom in anticipation of the construction of a dam and lock at Copperas Creek. Literally construed, these instructions would have required me to dredge the channel near Henry to a depth of about five feet, and gradually to diminish the depth as the work progressed down stream. The lower bars, which, by the way, were far the worst obstructions to navigation, would have been merely scalped, doing no good so far as immediate use was concerned. But as dipper dredges were used, which could not work in less than four feet of water, and as the work was mostly done when the river was low, there was of necessity a departure from the instructions, which departure furnished about all the practical value the work ever had. The instructions were subsequently modified to suit the situation, and the contractor was paid for all the useful work he did. After 1869 money was provided, by appropriation, for the improvement of the Illinois, by dredging and wing-dams, without mention of the proposed canalization, so that the work done was in the interest of a low water channel. The methods of dam construction, in which the use of brush was prominent, furnished the types and precedents for the construction of the earlier works on the Mississippi. In fact I came from the Illinois to the Mississippi to do what distinguished engineers said could not be done, build a dam across an important channel of the Mississippi, on a sand foundation, that would not settle indefinitely. It was done, and the possibility of improving the Mississippi thereby demonstrated.

Early in my connection with the Illinois River, I became convinced that the favored plan of improving by locks and dams was not advisable below Lasalle, and I became an advocate of an open channel, deepened so far as necessary by dredging and concentration, but looking to a future increase of volume by water drawn from Lake Michigan. As I had the efficient support of the steamboat interests and the tacit allowance of my superior, Gen. Wilson, the United States did nothing to forward the lock and dam project during my connection with the work. But later it did contribute to the work done by the State of Illinois at Copperas Creek, and afterward it undertook the construction of locks at La Grange and Kampsville. These last named works are not far advanced in actual construction, and in my judgment ought to be abandoned, or at least suspended, until the question of the scale of improvement is finally settled. Now they are included in the estimates submitted each year by the Engineer Department.

It has at all times been admitted that a waterway along this route should be maintained, but there has not been unanimity as to the scale of improvement, and possibly some desire to make it a means of giving advantage to one commercial point over another.

Officially, what is known as the Wilson-Gooding project has been adopted, though nothing has been done which commits the United States or the Engineer Department to the canal part of the project. The plan contemplates a 7-foot navigation, with locks 350 feet long by 75 feet wide. The river bed to be used below Joliet, thence to Lake Michigan by a canal fed from the lake, but the flow restricted to the quantity required to supply the wastes of the canal.

Opposed to this official plan is the Hennepin Canal scheme, which, under the guise of a canal to connect the lake at or near Chicago with the Mississippi at or near Rock Island, is, whether the truth is recognized or not by its advocates, a project to occupy the ground from Lasalle to Chicago with a so-called waterway that would bar the construction of a real one. The Hennepin project contemplates a barge canal 80 feet wide at the surface and 7 feet deep, with locks 170 feet long and 30 feet wide. If limited to a canal of these dimensions from the Illinois River at or near Hennepin to the Mississippi at or near Rock Island, this project is not objectionable, even from a St. Louis point of view. But when extended, as its most strenuous advocates always insist it shall be, of the same dimensions to the lake, it is a fraud, and should be opposed by the friends of waterways from all parts of the country, and especially by Chicago. As a branch to the trunk line, to which it is of secondary importance, Hennepin would escape unfavorable criticism, but when it is put forward as the trunk line itself, and as of primary importance, it is antagonistic to all interests (even its own), except those of the railways with which it pretends to compete.

A third plan, alternative to both of those named, covering whatever is of value in both, but going farther and meeting other and greater wants than they provide for, has recently come to the front. But as it has come forward more because of its connection with the drainage necessities of Chicago than of its commercial importance, it has encountered prejudices and inconsiderate opposition.

My purpose in this paper is to discuss, from a St. Louis point of view, this last and grander project in respect to its physical, sanitary, economical and political consequences, in contrast with its only practicable alternative, a navigation canal seven feet deep, with Chicago sewage entirely excluded.

Physical includes the effect on the lakes, on the immediate valley of the Des Plaines and Illinois, and on the Mississippi.

Sanitary embraces the consequences to Chicago, to the towns along the line, and those upon the Mississippi below the Illinois, including considerations of water supply and drainage.

Economical considers the effects upon industries and the movement of commodities.

Political takes account of the relation to defense and the uses of state, also the foreign and domestic influence of the improvement.

DESCRIPTIVE STATEMENT.

The project contemplates, First: A canal from Lake Michigan to the Des Plaines River, Joliet being the objective point, having capacity as a channel to carry a volume of at least 10,000 cubic feet per second, at a velocity consistent with the unimpeded use of the canal for navigation. Said canal to be the outlet for Chicago drainage, the volume being made ample to carry the sewage without objectionable polution.

Second: The improvement of the Des Plaines and Illinois rivers by a sufficient number of locks and dams, between Lockport and Lasalle, to enable vessels drawing 14 feet to pass at all stages of the rivers. Incidental to the building of the dams and to the increase of volume by a constant quantity, a water power of considerable magnitude will necessarily be created.

Third: The volume of water added to the Illinois will secure a sufficient navigable depth in the open channel, and so render the existing and proposed locks and dams below Lasalle unnecessary. These things being done, what consequences will follow?

PHYSICAL EFFECTS.

Of course, a discussion of the probable effect of withdrawing from lake Michigan, and from the St. Clair, Detroit, and Niagara rivers, of so large a quantity as 10,000 cubic feet per second, and transferring the same to the Illinois and Mississippi rivers, must be largely speculative at this time, but after proper observations and investigations, the questions involved can be definitely answered.

As to the effect upon the lake levels, we know that the discharge through the St. Clair River is approximately 217,000 cubic feet per second, which is the total coming from lakes Superior, Michigan and Huron. As Lake Superior is 20½ feet higher than Lake Huron and connected with it through St. Mary's River, its level cannot be affected by any diversion of the waters of Lake Michigan. Lakes Michigan and Huron are practically at the same level, if not absolutely so, but as the St. Mary's River empties into Lake Huron below the straits of Mackinaw, water from the Superior and Huron basins cannot be drawn to an outlet near the southern end of Lake Michigan, unless the outlet shall first take all the water from the Michigan basin. Lake Michigan has a water area of 26,000 square miles, and a direct watershed of 43,000 square miles, or a total of 69,000 square miles. The U. S. Lake Survey report (Primary Triangulation, etc., page 608), assumes that the Lake Michigan basin furnishes one-third of the water passing Detroit, or about 70,000 cubic feet per second. To be amply safe, I will assume that nine inches of water flows off from the area in dry years (the actual gathering of water in the reservoirs near the sources of the Mississippi is about this quantity), which gives a minimum flow through the Straits of Mackinaw of 45,000 cubic feet per second. To withdraw 10,000 feet per second at the southern end of the lake, therefore, will not stop the outflow through the straits, and since there is no perceptible fall, the lessening of the volume cannot draw down the surface except the two lakes are equally effected. Lake Huron cannot possibly be lowered more than by the trifling quantity required to adjust the slope of the St. Clair River, now only ½

inch to the mile, to the volume diminished by five per cent Again, the area of the two lakes is 50,400 square miles, and 10,000 feet per second would draw off one foot in 4.45 years, or at the rate of 2.7 inches per year. The conclusion is therefore safe, that the effect will not be noticeable, except as a result of a long series of observations, such as was required to establish the fact of a tide in the lakes. The actual decrease will be but a small fraction of the fluctuations of lake level due to other causes. Hence we may say, that the effect upon the lakes, that is, upon the depth at entrances to harbors and through the St. Clair channel, will be practically nothing. The international question can scarcely be raised, as the work and its immediate effect will lie many miles within our own territory, unless a perceptible lowering can be proven.

From Lake Michigan to Joliet the channel may be wholly artificial, in which case the only question is as to the area of cross-section and gradients; or the bed of the Des Plaines may be utilized for part of the distance, which will make it desirable that the flood waters of the upper Des Plaines be diverted to Lake Michigan. This diversion, if the quantity should be equal to that of the lake water taken into the canal, would leave the flood volume in the river, locally, the same as before, and no physical effect in this particular could be attributed to the works. Chicago's drainage and water supply will require this diversion, which has already been authorized by the Legislature of Illinois. The area whose flood waters will be diverted is about 500 square miles. From the data available, it appears that about one-half of the water coming from this area in extreme floods has always gone to Lake Michigan by the Ogden ditch and overflow through the Mud Lake Valley. The relief of the lower river by the diversion cannot therefore be estimated higher than 5,000 feet per second, or one-half of the proposed increment. It must also be borne in mind that the Des Plaines floods do not come at times to add their whole volume to the top of the floods from other tributaries, while the constant increment from the lake will augment the floods from every tributary at all times. Hence we are forced to the conclusion, that increase of flood volume at all points of the Des Plaines and Illinois rivers must be expected.

In considering the effect of an increment to the volume of the rivers, in the absence of observed data I will use estimates, but will take a maximum when dealing with floods and a minimum when discussing results upon channel depths.

At some time, geologically not remote, the Illinois Valley was the outlet of the great lakes, and carried a stream to which the present river bears but an insignificant proportion. The project looks to a partial restoration of the outflow of the lakes to the original channel, and so has no natural obstacles to overcome. The valley, as defined by bluffs, is from one to six miles wide. In some places floods extend from bluff to bluff, but generally they are limited, by high sandy prairies or gravelly terraces, to much narrower limits. These prairies and terraces are the bars of the former river, and furnish the sites for towns, and nearly all the cultivable land of the valley. The river bottoms proper are low and much cut up by shallow lakes and swamps. The river bed is a suc-

cession of deep pools separated by shoals. Some of the pools have the character of lakes, there being no perceptible current. At the shoals the current is decided but not strong. The flowage by the two dams already built does little real damage to land, though large areas are permanently covered by back water. If the scheme under discussion is carried out, the surface will be raised somewhat higher above Peoria than it is by the dams at Henry and Copperas Creek. The pools created by the dams are slowly filling with the débris brought in by the tributary creeks.

The capacity of the river bed above Lasalle to carry the increased volume need not be considered now. Since the arrangements will all be artificial, the conveyance of 10,000 feet in addition to the natural flow must be a condition kept in mind when studying the plans of dams and channels. But below Lasalle the natural bed must carry the ordinary flow between banks, and in times of flood the overflows must not practically extend farther or last longer than they do now.

Of the flood discharge of the Illinois, we have no direct measure. Taking differences between gaugings of the Mississippi at Hannibal and Grafton in 1881, the maximum difference of 79,000 cubic feet per second appears to be the greatest discharge of the Illinois in that year, if we neglect the several small tributary streams other than the Illinois. If so, we may assume that the greatest flood at the mouth discharges about 100,000 cubic feet per second. At lowest stage the natural discharge at the mouth was, by measurement, in 1866, about 1,200 cubic feet, which is now increased to about 2,000 by the water pumped at Bridgeport. At Lasalle, I know of no approximation to the flood discharge, except that given by Mr. Cooley, in his testimony before the joint committee of the Illinois Legislature, April 7, 1887, as a "preliminary estimate" of the flood of 1887. He said it was less than 58,000 cubic feet at Ottawa, and at Peru not over 60,000. The height of that flood was 26.4 above the natural low water, taken at 4 feet above the mitre sill of the lower lock at Lasalle. This height of flood is near the extreme known before the dam at Henry was built.

The area naturally tributary to the Illinois at Lasalle is 11,950 square miles; at the mouth the tributary area is 27,000 square miles. Since the contributions to floods per unit of area diminish as area increases, it is probable that the ordinary flood volume at Lasalle is about 50,000 cubic feet per second, but the natural channel cannot carry more than 25,000 or 30,000 at bank full stage. The addition of 10,000 feet at all times may not materially increase the height, but will certainly prolong the duration of overflow. It will also tend to take the river out of its banks oftener than would the natural volume. Against these tendencies, serving to increase floods, we may offset: First—The increased facility to flow, due to the removal of the dams at Henry and Copperas creeks. Second—The effect of channel enlargement, under the wear of a low stage volume increased from 2,000 to 11,000 feet per second. Third—Artificial increase of channel capacity by dredging bars and other work.

It has always been a matter of dispute and litigation whether dams increase the height of floods. They may or may not, according to the facts and circumstances of any particular case. If we bring before our minds

the curves of relation between heights on gauge and volume discharged, it is evident that the origin of the curve, or the level of no discharge, is, for the obstructed stream throughout the range of back-water, at the level of the crest of dam, and for the unobstructed stream at a lower level. The two curves at origin differ, for equal discharges, by the height of back water caused by the dam, and by a function expressing the difference in area due to a rise of one unit at the different heights. This function diminishes rapidly as height increases and practically disappears. The height due to back-water will cease to be perceptible when the flood so completely drowns the dam that no break in the surface is to be found. When this stage is reached the hydraulic conditions are the same as if the dam did not exist. Hence, in cases of comparatively low dams the height of extreme floods is not increased, but for lower stages the height for a given volume is greater with than without a dam. For medium stages in the Illinois there is an assured benefit from the proposed removal of dams to offset the increased volume, especially since the lower of the two dams backs the water to the upper one, consequently there is now some back-water at all stages.

The second set off is much more important, and merits more detailed consideration.

The first effect of adding to the quantity of water in a channel is to raise the level as measured by a gauge. If the supply be constant, there will ensue a new surface slope greater than before ; with the new slope comes an increased velocity, greater scouring and conveying power. It is a well established principle of river physics that a river traversing a bed whose material can be moved by the current will always create for itself a channel capable of carrying the normal volume of the stream. If the normal volume be increased, there will certainly be a corresponding increase of channel capacity. If there be no limiting conditions imposed by material of bed, the effort will be to bring the new permanent slope to an equality with the former, or slightly below it. Do such limitations exist in the Illinois? And, if so, can they be overcome?

Considered historically, the channel of the Illinois has deteriorated since it ceased to be the outlet of the lakes, and there is good reason to believe that the process of deterioration has not ended. From Henry to Peoria, and from Copperas Creek to Havana, the width, depth, and absence of current are more like a lake than river. In these reaches certainly the adjustment of bed to volume is not complete. A fivefold increase of low stage volume would arrest the encroachment upon the channel by deposit and vegetation. But it may well be doubted whether the current will be strong enough to enlarge the channel where too small for the increased volume. If it should be strong enough, it might not make such an enlargement as we would wish. We want the increase by bottom scour, not by lateral erosion.

From what we know of the Illinois it is probable that the addition of 10,000 cubic feet per second would at first raise the surface at Lasalle at least 10 feet. The normal fall from Lasalle to the mouth of the Illinois was formerly at low water in the Mississippi about 29 feet, distance 225 miles, giving a mean slope of 0.13 per mile. A 10-foot head rise would make the mean slope 0.17 per mile, but this small increase of slope gives

no clue to the acceleration of velocity or of the increase of abrading and transporting power at the places where work is needed. The matter is not one which can be expressed by formula; we must fall back upon experience, that the channel will ultimately be adjusted to the work it has to do. How long it would take the unassisted river to work out such adjustment is another matter upon which no opinion can be given. If we wish to realize results we must assist the process. Of one thing we may be sure, whatever assistance may be given in the way of hastening the channel enlargement, the reinforced natural forces of the river will maintain until the adjustment is complete.

What then are the possibilities of an enlarged channel? My experience in dredging enables me to speak confidently concerning the material found in the bed of the Illinois.

Some of the shoals are a sandy mud mingled with mussel shells to the depth reached in our dredging. The surface of such bars is well protected by the shells against being washed by the current. Other shoals are composed of a tenacious clay that is practically proof against such currents as the Illinois has or is likely to have. Another class of bars are of recent origin; indeed I have known of their coming into notice as the result of a single heavy rain. The material, in some cases, is the light soil and vegetable humus of the bottoms, in others it is sand and gravel. Of the several classes of shoals the last only present any difficulty in the maintainance of excavated channels, and the difficulty in these cases must be less if the tributary streams discharge their burden into the fuller river and quicker current of the augmented stream, than if into the slow current and dead water caused by the dams. Hence this class of bars furnishes no argument against the proposed form of improvement that is not much stronger when applied to the only alternative plan.

The shelly shoals and the tenacious clays will, in my judgment, require the assistance of dredging. With such assistance there is no limit to the depth attainable except the resources of the government, and willingness to apply them to the work.

SANITARY EFFECTS.

The proposition to create an artificial river and to discharge into it the sewage of a city, which expects to become one of the largest cities of the world, is one to be carefully considered from the sanitary point of view.

Chicago is daily demonstrating its ability to pollute a large body of water to an unbearable degree. Chicago River, within the city limits, has an area of 453.1 acres, of which 110.5 is not seriously polluted; the remainder, 342.6 acres, is more or less charged with sewage. The contents of the more active channels are changed nominally, in periods varying from 30 to 80 hours; but some of the slips cannot be said to come within the feeble circulation that is supposed to renew the water; also the South Fork has no circulation other than that due to the sewage discharge, measured by the water supply, which would renew the contents in about two weeks. Into this body of water the sewage of about 700,000 people is now being discharged. The amount of dry organic matter of human origin is estimated at 122,000 pounds daily. Other sources will probably bring the total amount of putrescible matter up to

400,000 pounds per day. The offensiveness of Chicago River sufficiently accounts for the desire of the city to be rid of the nuisance at any cost; it also fully accounts for the fear of other communities, along the proposed line of drainage, lest the nuisance be transferred to their doors. Bad as the smells are, there is a possibility of worse results than any cognizable by the senses. What may we reasonably expect if the proposed plan is carried out?

It may be well here to call attention to a distinction between offensiveness and unsanitary. A very bad smell may produce nausea at first, but one may become habituated to it and no evil follow. A disease laden exhalation may, on the other hand, not give any warning to sight or smell. Just as is the case with water, it may be so muddy as to be disgusting, and yet be wholesome; or it may be clear and sparkling and be laden with disease germs, or carry a pollution of the filthiest origin. Again, the conditions under which human beings, habituated to filth, can live, and apparently thrive, would be speedily fatal to others more delicately organized. The higher the organization the more sensitive to unfavorable surroundings it becomes. In the interest of that larger statesmanship which looks to the healthy development of generations yet unborn, it is important to solve this drainage problem aright. The quality of the men and women who are to dwell in the valley of the Illinois and lower Mississippi, may depend upon the answer given to the question discussed in this paper.

Regarded in the aspect of offensiveness, the study of the Chicago drainage problem has shown, that a flow in the river equal to 15,000 cubic feet per minute to each 100,000 inhabitants secures a condition that is hardly satisfactory in the Chicago River, a flow of 9,000 per 100,000 produces an intolerable condition. The proposed 10,000 cubic feet per second, or 600,000 per minute, would be 24,000 per 100,000, if the population to be provided for be estimated at 2,500,000.

With such a volume passing through the canal, and a large part of it through the Chicago River, sewage would undoubtedly pass beyond the boundary of the city within 12 hours of its production, consequently before the processes of decomposition can be far enough advanced to produce offensive smells. Hence we may confidently say that the plan will secure the cleansing of Chicago River, and solve the local problem.

But will the harmless condition continue through the canal and river?

First of all we must take note of the fact that the Chicago River is not capable of carrying the proposed volume from the lake to the beginning point of the present canal, nor can it be deepened to the standard of depth proposed, 24 feet, without destroying the tunnels for street traffic at Lasalle and Washington streets. There will have to be a new canal from the lake capable of carrying the greater part of the proposed increment, into which the river must discharge. The volume passing through Chicago River would necessarily be large enough to keep the condition tolerable, and bring the sewage to the main canal in a comparatively fresh state; it would then be diluted with clean water and be started on its way, under circumstances more likely, in my judgment, to secure inoffensiveness than if the whole volume traversed Chicago and received the primary discharge of the sewers.

The decomposition of sewage depends upon oxygen, or, as later biological investigations indicate, upon some forms of bacteria. Doubtless oxygen and these lower forms of life go together. We know that water which has been polluted may be purified so as to be clear, but fish placed in it will drown. The life supporting element has been consumed by the process of decomposition that has taken place and it requires a fresh supply of oxygen. In Chicago River we have an instance of exposure to light and air with no inconsiderable amount of agitation, but no progress toward purification ; on the contrary, so far as dilution and aeration now go, the condition becomes worse and worse. Partial decomposition of contained sewage by purifying processes seems to change the whole body of water into sewage, though but a small part has traversed the sewers. A second dilution will bring a fresh supply of bacteria and oxygen.

It again is to be remembered that an indispensable condition will be that all solid matters be kept out of the sewage. Garbage, and, indeed, everything capable of cremation, must, in the near future, be so disposed of by all cities. The slaughter and packing houses of Chicago are already adopting improved processes by which former wastes are utilized, and the city has a garbage furnace in successful operation. I think we may safely say that the greatest concentration of sewage has been reached, and that the exclusion of matters that have heretofore gone into the sewers will materially simplify the question of disposal, and render the effect of dilution more definite.

Decomposition of fœcal wastes under the water carriage system must take place. With a proper degree of dilution, we know that this process can go on without offence, and it is believed that the proposed dilution will be sufficient. But there must remain a doubt whether, in the case of typhoid and perhaps other germs, dilution in any practicable proportion will render water once contaminated by sewage safe for drinking. When we know more concerning this branch of the subject, it may be necessary to disinfect the sewage of all towns that discharge into rivers which are the source of domestic water supply to towns below. This is no more applicable to Chicago sewage than to that of St. Louis.

The question before us is hardly one in which absolute safety can be demonstrated; but when we consider relative conditions, the matter is more definite. The sewage of Chicago has for several years been delivered into the Illinois and Michigan canal (in part since 1860, in greater proportion since 1871, and wholly since 1883), and has followed the proposed route: hence we can have the benefit of experience, upon the question of relative conditions, present and proposed.

In 1879 the quantity of water passing through the Illinois and Michigan canal was about 9,000 cubic feet per minute. At Joliet, 33 miles below Bridgeport, the water falling over the dam gave off odors comparable to those arising when a privy vault is being emptied. When the river was frozen a percentage of sewage was discoverable as far as Peoria, 160 miles. The condition was so intolerable that the Legislature required Chicago to erect pumping works, as a condition of being allowed to continue the discharge of sewage into the canal. As a result of an increase of volume to 45,000 cubic feet per minute, sewage, in 1886,

could not be traced farther than Ottawa. We have then a practical demonstration of the efficiency of dilution, an efficiency which must certainly increase in a greater than arithmetical ratio. The present degree of dilution is 1 : 4, sewage to lake water. The proposed dilution, when the population of the metropolitan district shall be 2,500,000, will be 1 : 18. This is a mixture that could not be recommended as a drinking water; but it is vastly better than now. Under present conditions offensive pollution, evident to the senses, can at low water be traced about fifty miles, chemically it is not discoverable eighty-one miles below Bridgeport; but in winter the pollution extends farther. The mean condition is fairly well represented by the following results of analyses made under the State Board of Health, reported at quarterly meeting October 28, 29, 1886.

IN 1,000,000 PARTS.

Locality.	Free ammonia.	Albuminoid ammonia.	Oxygen used.	Number of analyses.
Chicago (lake)	0.00230	0.0678	1.2000	10
Bridgeport	17.44000	1.1952	20.5800	10
Lockport	10.23000	0.6690	11.3020	10
Joliet	6.93300	0.4080	7.7780	9
Ottawa	0.38175	0.2375	5.5750	8
Peoria	0.03557	0.1877	4.8457	7

Taking the analyses of specimens collected at each place on the same day :

Locality.	Free ammonia.	Loss, per cent.	Albuminoid ammonia.	Loss, per cent.	Oxygen used.	Loss, per cent.	Miles.
Bridgeport	26.563		1.6330		26.30		
Lockport	12.733	52.1	0.7530	53.9	11.91	58.0	29
Joliet	9.426	26.1	0.4320	42.7	7.34	33.4	4
Ottawa	0.413	95.6	0 243	43.8	5.30	27.8	48

Total per cent. of loss in passing from Bridgeport to Joliet, 33 miles : Free am., per cent., 64.6 ; alb. am., per cent., 70.36 ; ox. used, per cent., 72.

Our interest is chiefly in the condition of the water, after the pollution by Chicago sewage is supposed to have disappeared ; hence comparing Ottawa and Peoria :

Date. 1886.	Free ammonia Ottawa.	Free ammonia Peoria.	Album. ammonia Ottawa.	Album. ammonia Peoria.	Oxygen used. Ottawa.	Oxygen used. Peoria.
June 26	0.50	0.036	0.23	7.15	7.05	5.04
July 10	0.22	0.084	0.164	0.15	4.96	5.04
July 31	0.49	0.0048	0.25	0.196	6.00	4.64
Aug. 7	0.52	0.0072	0.32	0.21	6.40	6.80
Aug. 14	0.30	0.042	0.144	0.19	4.80	4.72
Aug. 28	0.36	0.009	0.33	0.206	3.12	2.80
Mean	0.398	0.031	0.2396	0.1836	5.388	4.84

The stage of water covered by the observations was unusually low. Dr. Rauch, Sec. Ill. State Board of Health, says : "It is entirely safe to say that there was no Chicago sewage pollution of the Illinois River at these points (Ottawa and Peoria), and similar observations made during the freshet period, February and March, 1886, showed no trace of Chicago sewage."

With this evidence of the disappearance of pollution, there remains only the statement that offensiveness can be noticed at Peoria and at all points above when the river is frozen.

When the river is frozen, the volume is usually small, the current feeble, the ice cover effectually excludes light and air, and the low temperature is unfavorable to decomposition. The conditions approach

that of a closed conduit carrying a constant quantity. For all we know sewage could be conveyed in a closed conduit for indefinite distances without change in its character. But we can safely say that increase of dilution will diminish the nuisance in winter as well as summer. Hence an improved sanitary condition may safely be predicated as the result of the plan, if carried out. In the portion of the river now unaffected by Chicago sewage an improved sanitary condition may be expected to follow the removal of the dams, more decided perhaps than will be realized in the parts where the sewage question is debatable. Replacing the stagnant condition caused by the dams by an active current and greatly increased volume during the hot months must do away with much occasion of malaria. The bottoms are generally low and interspersed with large areas of swamp or shallow lakes. The back water of the dams materially increases the area of shallow flowage, just deep enough to encourage vegetation, and during the hot season to favor the escape of gases generated by decomposing vegetation. Decomposing vegetable matter in disgusting masses now floats in the water, and under the action of winds is driven to the shores, where it gives off odors as offensive as sewage, and probably more unhealthy.

From this brief discussion of the sanitary side of the question, I am led to conclude that there need be no fear of offensive pollution or any danger cognizable by chemistry. If there be an element of risk it comes within the province of biology, and is at present too uncertain to be estimated. This risk will be limited to the use of the river water for domestic supply, and can be avoided by thorough disinfection under public authority of the sewage coming from houses in which infectious diseases occur, a precaution which must be adopted for other reasons everywhere. The general sanitary condition, as measured by decrease of malaria, will surely be improved.

Aside from the betterment in general of the malarial condition, the water supply of the towns along the route will be materially improved by the adoption of the big waterway, instead of the lesser. If Chicago sewage is left out of the question the water of the Illinois is unfit for domestic use, but the towns act as if they had no choice and use it. Some of them would do better by a driven well system, for there is a water-bearing stratum accessible. The towns down to, and including, Peoria should use this ground water in preference to that of the river. I fear this source of supply is not available much below Peoria. Bad as the Illinois water is naturally, the towns will, as they arrive at the period of growth when sewering becomes necessary, pollute it to a condition as bad as Chicago River even if Chicago sewage be excluded. The natural low stage volume at Joliet is, for months at a time, less than 1,000 cubic feet per minute. Joliet now has about 20,000 inhabitants and expects a rapid future growth. Taking Joliet by itself the flow now would be at the rate of 5,000 feet of water to 100,000 inhabitants. But the Des Plaines is and will be polluted before reaching Joliet by the growing suburban towns in the Des Plaines watershed, hence an intolerable condition may be clearly foreseen. From the list of principal towns in Illinois in 1880, it appears that the Des Plaines, Kankakee, Fox, Vermillion and Illinois rivers above Lasalle have the drain-

age of fifteen towns with an aggregate population of 60,270, to which we must add Lasalle, 8,988; Peru, 5,067; Henry, 1,728; Lacon, 1,814; Chillicothe, 936; Peoria, 29,319; Pekin, 5,998; Havana, 2,118, and Beardstown, 3,136: total, 119,364. At Lasalle the natural low stage flow is not more than 38,000 feet per minute. The urban population, including Peru, was 75,000 in 1880. At Peoria the discharge is but little greater, and the population in 1880 was 108,000, probably over 150,000 now. With these facts in mind, what is the probability of having potable water in the Illinois at any point of its length, when the density of population in the tributary country shall have increased to that of Europe or even New England? So far as St. Louis may be interested in the condition of the water coming into the Mississippi from the Illinois, these facts should receive careful consideration. To the above view of the inevitable condition due to pollution add the stagnancy due to the proposed series of dams, and I think all will agree that the sanitary argument is against the little and decidedly in favor of the big waterway.

ECONOMICAL RESULTS.

A waterway of capacity virtually extending the Mississippi at its best to the lakes must of necessity be of moment in the matter of trade movements. It contains a potency that is capable of changing their direction when supplemented by developments sure to come with time. The result may be considered with reference to the effect upon the trade of a particular locality, or, more broadly, with reference to the trade of the country. To forecast results of this character is scarcely within the province of the engineer, and I shall not undertake more than to point out a few possibilities.

Our present ideas of trade movements are based upon an European market for breadstuffs and provisions, and the Atlantic States as the source whence manufactured products chiefly come. I do not think these conditions permanent. The last few years have seen a woful decline in the price of breadstuffs and the closing of European markets to our provisions, the former at least caused by competition with new sources of supply, which have been opened by extension of railways in India, Russia, and the Northwest. The competition has come to stay, and in the end the direction of our trade will change to new foreign markets with new commodities, and by the development of the home markets. Gas fuel, natural or manufactured, is another element that is likely to change the course of trade, by transferring the seat of manufacturers from the East to the central West, where abundant coal deposits invite the manufacture of fuel gas in localities where the natural cannot be had. The water power created along this canal, about three times that afforded by the Mississippi at Minneapolis, and correspondingly greater than the power at Lowell and Holyoke, will invite a beginning of the change of manufacturing centres. Raw material, as accessible here as elsewhere, cheap food, and the central position with reference to distribution of manufactured products, are potent factors in bringing about a new location of trade centres, whose effect may not be fully realized in a single generation but is sure to come. We, in this matter, are not building for to-day merely.

By natural position, at the point of division, at the water-shed, so to

speak, Chicago will be at the principal focus of the new trade world. St. Louis will be on the main commercial line and in the field of industrial activities, hence she should speed the day of change as the day of her best opportunities.

St. Louis has often been charged with opposing improvements on insufficient grounds, simply because she suspects that they may be injurious to her interests. The charge means no more than that St. Louisans are human. To this instinct her uncompromising hostility to the Hennepin scheme is largely due. Chicago has, under a mistaken idea of her interests, heretofore promoted that project with influence and money. Lately, through the intelligent efforts of her civil engineers, Chicago's influence has been turned in favor of the grand waterway I am discussing. St. Louis engineers have now an opportunity to prove their value in the community, by ascertaining how St. Louis interests will be affected, and bringing this community to an intelligent position toward this subject when it comes up for consideration in Congress, as it probably will next winter. A Senate amendment of the River and Harbor Bill orders a survey of the route and study of the project I have presented in this paper.

Unfortunately a deep-rooted prejudice exists in St. Louis from an unnecessary association of a waterway to the lakes with Hennepin, and more recently on account of Chicago sewage on the part of those who do not know that so far as Chicago sewage can affect us we have had it in full measure for five years.

I have already said that Hennepin, as usually presented, is antagonistic to this large waterway project, but the converse is far from true. The large waterway will readily swallow any contributions to its traffic that may be brought by way of the proposed Hennepin Canal from the upper Mississippi, and will stand ready to forward it north to Chicago or south to St. Louis with entire impartiality. The goods will go to the best market. I, for one, do not believe that the use of the Hennepin Canal, if built, would in tons and bushels either make or mar the fortune of the city to which it may chiefly go. This great waterway is a project of another sort. It seeks not the trade of any section and its benefits must not be sought in the history and movements of the products of any locality, but rather in the grander movements which it will stimulate. The share of different cities in the resulting business will not be equal, but all can have a share and be the richer for that share.

The project before us proposes a depth for navigation of not less than 10 feet, preferably 14, with practically no limit to length or breadth of vessels. Locks, say 450 × 80 feet. The Canadian canals have locks 270 × 45 × 14 feet. The United States improvements of lake ports and the channels through the Detroit and St. Clair rivers contemplate 20 feet draft. The proposed channel would pass the largest lake vessel light, and most of those now in existence loaded. But I do not anticipate a commercial use of the route by lake vessels. It would open a way by which such vessels could seek employment during winter in trade between the Gulf ports and the West Indies or Central and South America, and so powerfully aid in building up such a trade. The actual traffic through the canal I think would mostly be carried by barges.

In this connection it is proper to consider the suitability of the proposed channel for navigation. The canal is to have capacity to pass 10,000 cubic feet per second at a velocity not greater than two miles per hour, three feet per second. The section must be about 3,300 square feet, and several alternative suggestions have been made. The Chicago Drainage Commission proposed 200 feet surface width by 18 feet in depth. The representatives of the Illinois and Des Plaines valleys demand 160 by 22, and Mr. Cooley has suggested 150 by 24. The first and last represent about the extremes. The amount of excavation above water line is a potent factor in limiting width, by increasing cost. On the other hand, the surface width, for the passage of vessels at speed, cannot be reduced below 150 feet.

Assuming, for illustration, that the depth of excavation above the standard water line will average 10 feet, the three sections named will call for a prism of excavation of 5,600, 5,120, and 5,100 square feet, respectively. The proportion of rock to earth will certainly increase, and with it the cost, as the section is narrowed and depth increased. If the river part of the route is to have a depth of 14 feet, then I do not see any material gain from a depth of canal more than fifty per cent. greater than the maximum draft of vessels. This consideration, together with the increased freedom due to 10 feet more width, inclines me to prefer the section 160 × 22 feet. With that depth the canal from the lake to Joliet would be accessible to the largest lake craft at all times.

The current of two miles per hour will be somewhat against northbound traffic, but will be little in excess of the current that must be met by such traffic in ascending the Illinois, and is much less than encountered in the Mississippi, so that looking at the route as a connection between the Gulf of Mexico and the great lakes, the current in the most northern 29 miles is of little real consequence.

The proposed increment of volume in the river below Lasalle will probably add to the natural low water depths about as follows:

Locality.	Natural depth.	Increase.	Channel depth.	
Lasalle	1.25	10.75	12	feet.
Hennepin	1.50	9.50	11	"
Lacon	4.00	8.00	12	"
Peoria	3.50	8.00	11	"
Beardstown	3.00	6.00	9	"
Westport	3.00	4.00	7	"
Mouth	4.00	2.00	6	"

The deepening of the channel by scour would first be felt in the lower part of the river, where the quickening of the current would be the most marked, also because the shoals in the lower part of the river are of material more readily acted upon than those above. A deepening to afford 10 feet draft at the lowest stages may confidently be expected throughout the Illinois, as the result of natural forces supplemented by a reasonable amount of dredging and concentrating works. The increment of volume will also materially benefit the Mississippi. Ordinary low water volume in the Mississippi at Grafton may be taken at 30,000 cubic feet per second. By the discharge curve, derived from the observation of 1881, $Q = 449G^2 - 4404G + 8062$. The discharge of 30,000 cubic feet corresponds to a height on gauge of 13.4, at which stage the differential for one foot change of stage is 7,530 cubic feet per second; hence

the increment will be enough to raise the stage one and one-third foot, adding that much to the channel depth in the Mississippi apparently. Boatmen tell us that their experience is that one foot rise out of the Illinois gives double increase in channel depth below the Illinois. whereas a foot rise on the gauge at low stage, the water coming from the Missouri, will rather diminish than increase channel depth. This difference is attributed with reason to the fact that the Illinois furnishes clear water, the Missouri silt laden. The proposed increment being clear water after the process of channel enlargement is complete, we have reason to expect an increased depth in the channel from the Illinois to the Ohio at least equal to the computed increase of height on gauge at Grafton. My firm belief is that the increase of the low stage volume below the Missouri by the one-sixth part will benefit the channel much more by scour than by direct raising of the surface.

Tracing the possible effect, I obtain from discharge curves the following:

Locality.	Low stage volume.	Volume to raise one foot.
St. Louis	60,000	10,500
Columbus	130,000	16,400
Fulton	131,000	19,550
Memphis	132,000	21,400

From these figures one is justified in saying that the beneficial effect of the increment can be traced as far as Memphis. In fact the volume required to raise the river one foot is greater at Memphis than at any lower point until we approach Carrollton, where a foot rise requires nearly 44,000 cubic feet increase of volume.

The increase of volume will have an important economical effect by creating water power along the part of the route lying between Lockport and Ottawa. The fall is 145 feet, the volume will be reliably constant and the horse-power available will be, between Lockport and Lake Joliet, about 50,000, and between Lake Joliet and Ottawa about 40,000. The natural water privileges along this part of the route have fostered several thriving manufacturing towns; we may therefore expect that the more valuable power created by the canal will be utilized. The industries so brought into existence will add to the trade along the route and to the general prosperity of the country.

POLITICAL EFFECT.

All now admit that transportation routes bind the country together more firmly than any other agency by fostering community of interests. As a matter of internal politics it will be well to complete this north and south bond. So long as we have a neighbor to the north whose interests are not identical with ours, there is a possibility of breach of friendly relations, and as a matter of prudent outside politics, it would be well to have a way open by which a defense for our lake cities can be provided without breach of existing treaty obligations. With the Illinois waterway improved upon the scale proposed, we will always have it in our power to meet our neighbor on the lakes upon terms of equality. If any lesser scale is adopted, we deprive ourselves of the only opportunity to secure equality short of maintaining a lake fleet and costly fortifications.

One word in closing as to the division of the burden of construction.

The United States might with propriety do it all, but if any municipality can see a benefit from anticipating the action of the general government, and in doing a specific part of the whole work, there can be no reasonable objection to its doing so. Chicago, in view of the delays attending the execution of public works by the United States, will be compelled to excavate the channel from the lake to Lockport. And it is by no means certain that associated capital may not solicit the privilege of doing that part of the work, looking to enhanced values of land along the line and control of dock privileges for compensation. In addition to these possibilities, the State of Illinois might find in the construction of the canal the solution of the trying political question, what to do with the labor of convicts in the penitentiary at Joliet. If any of these plans be followed, the United States will only have to prepare the Des Plaines and Illinois to receive the increased flow and to provide the locks needed between Lockport and Lasalle.

FAILURE OF A FIRMENICH BOILER.

By Chas. F. White, Member of the Engineers' Club of St. Louis.

[Read May 16, 1888.]

On the morning of October 3, 1887, a boiler at Plant's flour mill in this city exploded with great violence and fatal results. This explosion excited considerable interest among engineers and steam users, from the fact that the boiler was a form of the water-tube type but recently brought into use in St. Louis. As a water-tube boiler it was put upon the market as one free from the danger of disastrous explosion. As it is a generally accepted opinion that water-tube boilers are more safe than those of the fire-tube type, I have endeavored to find, if possible, the immediate or remote causes of this occurrence, and to point out the sources of danger in similar boilers in use about the city.

Many of you may recall the accounts given at the time of this explosion, and some examined the premises after the accident. For others I will briefly describe the situation and the physical aspect of it. The mill itself is a brick structure about 75 feet high, occupying the northwest corner of Main street and Chouteau avenue; between the west end of the mill and Risley street, occupying the northeast corner of that street and Chouteau avenue, was a one-story building used for engine and boiler rooms. The floor of this part of the building was about 8 feet below the street level ground. The engine room was next to the mill, and the Firmenich boiler was placed close up to the west wall. A Babcock and Wilcox boiler occupy the space between the engine-room wall and the Firmenich. Steam from each boiler was carried to a large receiving drum suspended in the engine room, and from this was carried to the engine.

The details of the boiler room, viz., safety valves, feed pumps, feed water heater, gauge cocks, glass water gauges, etc., were well provided and suitable for the duty required of them.

Both boilers were under steam and in service.

The Firmenich boiler in this case consisted of a pair of horizontal drums at the bottom, about 6 feet apart; also a pair of similar drums, some 2 feet apart, parallel to the first pair, but at a height above them of about 15 feet. The upper and lower drums were connected by 126 tubes, 3 inches in diameter and 16 feet long. The upper drums being nearer together than the lower ones, the tubes were not upright, but inclined like the legs of the letter A. These water tubes were placed in four rows on either side. The four similar drums were 16½ feet long each by 7½ feet perimeter, and in section were about three-fifths of a circle, the chord forming a flat surface for the reception of the water tubes, which were expanded into the tube sheet so formed. A large water-leg near the rear connected the lower drums, while above the upper pair was a steam drum having two connecting legs on either side opening into the upper water drums. The water level in this style of boiler is about halfway the height of the upper drum, and the feed water was introduced into the boiler just below the water line in these drums.

The furnace was in the space between the water tubes extending from side to side, and back about half the length of the boiler, more or less according to the amount of grate surface needed. About two feet from the rear of the boiler a brick curtain formed the bridge-wall rising nearly to the upper drums. The whole structure was surrounded and covered with brick walls forming the furnace walls and ends.

An examination of the wreck immediately after the explosion seemed to show that the boiler gave way along the edge of the tube sheet on the upper drum on the east side. This is evidenced by the fact that the four legs connecting the steam drum with the water drums had crushed in the shells of the drums, although all of them were found torn from their fastenings.

The steam drum was not much damaged itself, but was thrown with such force as to land much like a rocket stick on the roof of a two-story dwelling house some 200 feet distant, through which it plunged into the cellar. This house stands on the west side of Risley street, the direction from the boiler house being west of north. The west upper water drum was thrown in a direction almost due west, passing diagonally through the roof of a two-story stable, and lodging part way through the west wall of the building. This drum was torn apart at the middle circumferential seam, but not much ruptured otherwise. The upper drum on the east side of the boiler was thrown in a direction a little north of east, or nearly opposite to that of the other drum. It must have risen in a path nearly vertical, since it was found nearer where it started from than the others were; yet it must have passed clear over the top of the mill to reach the place where it fell on the railroad track north of the mill building. This drum was not torn in two entirely, but was ruptured and much spread out along one edge of the tube sheet. No one could view the condition of this part of the wreck and fail to get a very vivid impression of the force that had been acting upon it, so much was the iron shattered and torn. The tubes of the boiler were for the most part left standing in their places in the lower drums. Some were thrown about and some were bent, probably by the

wreck of the building. The houses on the west side of Risley street, opposite the boiler house, were about half blown down.

The walls of the boiler house were thrown out in each direction. The roof was partly thrown over against the mill building, a circumstance that saved the life of the engineer. The mill building itself was almost uninjured, the force of the explosion finding vent chiefly to the west. The structure of the Babcock & Wilcox boiler acted to some degree as an anvil to take up the force on the east side. That boiler was somewhat crushed and broken, but did not in any sense explode. The lower drums of the exploded boiler did not move much from their positions.

Here, then, we have a boiler of the water-tube type, with no very large body of water or steam in one shell, which, instead of failing in some minor part, as it is supposed such boilers should, without damage to the whole, has shown itself fully equal in destructiveness to the Mississippi steamboat boiler in its palmy days. I believe this is not the first case of the explosion of a Firmenich boiler. The facts show plainly enough that even the comparatively small drums used are large enough to hold plenty of destructive energy if it is permitted to escape control. It is of value to know if this particular form of boiler has elements of weakness peculiar to itself, and how far will causes at work in this case affect other forms of water-tube boilers.

Naturally enough a first thought is that some neglect of duty by those in charge of the boiler was the direct cause of the disaster. The fireman on watch that morning was killed, but the mill engineer was on duty, and was in the boiler room but a short time previous to the explosion. This engineer, the night fireman and two others recently employed there were examined under oath by the City Board of Engineers. A carefully prepared series of questions, covering the occurrences of that morning and also the usual practice in care of the boilers, was answered categorically, beside other questions. The testimony of these men was, I think, plain and consistent. I have not been able to find any reliable evidence that any proper precaution was neglected or that the boiler was injured through lack of care. The only man who could give the whole story was the engineer, since the fireman lost his life. The account given is substantially this. The day previous the boilers had been shut down to allow replacing a leaking tube in the Babcock and Wilcox boiler. The boilers were filled with water the night before, the Firmenich being filled somewhat too full. At 5 o'clock Monday morning the fires were lighted. At 5:45 the water in the Firmenich boiler was drawn down to a point a little below the top of the glass gauge. At 6:10, there being some steam pressure the engineer went to the top of the Firmenich boiler to examine and tighten the gaskets in the manholes. While there he tried the gauge cocks, finding water at the proper level. An hour later, at 7:10 A. M., the mill engine was started. After running some ten minutes the miller rang to stop the engine for some cause in the mill. It was ten minutes before the signal to start again came. Having started the second time the engineer went into the boiler room and looked at the condition of the fires, and directed the fireman to put coal on each fire. He also looked at the water in each glass gauge, each one showing water at the ordinary height. The steam gauge registered

ninety-five pounds. The safety valves were set to blow at one hundred pounds pressure. The one on the Babcock and Wilcox boiler, however, opened slightly sooner than the others, and had previously been threatening to blow, although no discharge had occurred that morning. The engineer went back to the engine-room, passing behind the cylinder of the engine, reaching that position about five minutes after starting the second time. The explosion came just at that moment.

The boiler was built of lap welded tubes and iron plates. The plates were three-eigths of an inch thick and were stamped Central Iron Works, Harrisburgh, Pa., C. H. No. 1, 45,000 pounds tensile strength. Seven test specimens were cut from the tube sheet of the east drum. Five of these specimens were cut lengthwise the sheet, two across the grain. These were broken in the Testing Department at Washington University with these results :

	1.	2.	3.	4.	5.	6.	7.
Breaking strength...	52,800	58,900	55,400	51,700	50,100	55,700	56,800
Elastic limit........	26,700	34,000	31,700	29,600	34,700	41,300	40,000
Elongation, per cent.	......	....	......	12½.	6	8	......
Reduction of area, per cent..........	4	2⅜	28	37	31	28	23

Average tensile strength with the grain, 539,940 pounds.
Average elastic limit, 35,400 pounds.
Per cent. of elongation in 6 inches, 8.83.
Per cent. of reduction of area, 29.4.

These tests do not give as uniform results as might be desired, but the plate from which the tests pieces come had been subjected to some treatment, and taken together they do not give us ground to believe that the iron was inferior in quality for the work expected of it, the strain due to 100 pounds pressure in a 30-inch drum of three-eighth inch plate being 4,000 per square inch of section.

It is not easy to judge of the workmanship put into the construction of a boiler examined after such a wreck. I have not found any strong evidence of defective workmanship in this one. I have endeavored to learn what the regular duty required of the boiler outfit was, and while exact figures are not to be obtained, I think I can make a fairly reliable estimate. The Babcock & Wilcox boiler had 2,600 square feet of heating surface and was rated at 250 horse-power.

The Firmenich boiler had 3,375 square feet of heating surface, and was rated at 225 horse-power.

I was not able to secure indicator diagrams taken during the time that the boiler in question was in use, but was told that there was seldom more than 500 horse-power used.

The mill water-meter for six months previous to the explosion showed a consumption of about 8,000 pounds of water per hour. Nearly all of this goes to the boilers, and they also use some condensed water, but I cannot from this source find warrant for assuming that 500 horse-power was regularly required of these boilers.

Probably on the average the evaporation per square foot of heating surface from these boilers was about 2 pounds an hour, a rate which cannot be regarded as excessive. But there may have been times when they were overcrowded, and also we cannot tell just what proportion of

the whole each boiler performed. The opinion of the engineer was that the Babcock & Wilcox boiler did the larger share of the duty.

We are now brought to a consideration of the design and construction of the boiler and its operation in practice.

It will be noticed that the drums at top and bottom are not of a circuluar section, but are flat on one side; in the case of this boiler, the flat part being nearly the diameter of the drum. Two such drums are connected by straight water tubes in four parallel rows The whole of this structure is subjected to internal pressure. This pressure, acting on the area of the open tubes. tends to force the drums apart, making a tensile strain on the expanded joints. The internal pressure also makes an effort to bring the drum into a circular cross section. The resisting force opposed to this is also the expanded tube joints. It will also be seen that the real net effect of the internal pressure is to cause a pull upon the outer row of tubes considerably greater than would be the case with the fire tubes of a shell boiler spaced in the same way. The more so since the pressure tending to bulge the flat tube sheet acts through a longer lever arm than does the resisting tube.

But a more serious cause of severe strains in this structure is that of the unequal heating of the water tubes in various parts of the boiler, these water tubes being so fixed at the ends as not to be free to move.

I think it plain that two causes contribute to this result.

The first is that the fire in such a boiler is near one end, exposing the nearest tubes to a very intense and direct heat. Where four rows are used, as in this boiler, two of the rows are well shielded from radiant heat, and are also well out of direct currents of hot gases.

In the boiler in question, all tubes that have failed and required replacing were a little back from the front end and in the row next the fire. Internal incrustation is another cause of overheating, which, in this boiler. means undue expansion, and hence severe strains.

All persons examined agreed in the statement that heavy firing or unusual heat, such as is caused by breaking down a fire, always caused a strong pulsation of the water level in the glass gauge ; the water sometimes disappearing and then raising 12 to 15 inches with a regular wave motion. I have elsewhere noted a jet-like pulsation in the flow of mingled steam and water from a heated tube. Should such motion ever leave a tube partially free of water, as can readily be imagined in a tube of a length of more than 50 diameters exposed to high heat, the scale would be at once hardened on the internal surface. That the scale does so harden to such a degree as to very nearly fill the tubes in Firmenich boilers, is a well-known fact to users of that boiler in St. Louis.

Here then are to be found the causes of the disastrous failure of this boiler, and these elements of weakness are at work with more or less effect in all such boilers now operated here. Moderate working and careful watching at all points may prevent the repetition of such an explosion, but I think it is beyond question that the design is a faulty one and unsafe to be put upon the market.

It is to be noted that when any form of water tube boiler is used where the water contains scale-producing elements, this scale is very liable to be deposited on the walls of the tubes, and it is not easy to remove it

when once hardened. A fire tube receives its deposit of scale on the outside while hot and expanded. Cooling down as during cleaning tends to loosen such scale. With a water tube the reverse is true. The scale is deposited on the inside while the tube is expanded, and upon cooling the incrustation is firmly held by the contracted tube. Cases have occurred in St. Louis, I believe, where it was easier to replace the tubes than to get the scale out of the inside, where it was held almost like solid stone. Under such conditions it becomes very important that the distribution of heat be uniform in amount on the tubes, especially on those in proximity to each other, or that the tubes be free to expand without setting up strains in the structure of the boiler. I have thought it worth while to compare the boiler under discussion with one or two other forms of the water tube type in the points specially noteworthy. These are distribution of heat and freedom of expansion. Reference has been made to the Babcock & Wilcox boiler, of which quite a number are in use in the city, and which is typical of several other makes. With this boiler the tubes are in sets, each set extending from the top to the bottom of the tube system, the tube of each set being connected by a steel casting. Each set then is free to expand independent of those alongside. In this style of boiler the heat of the fire is nearly equal across the entire width of the boiler, and the hot gases crossing the length of the tubes three times bring a reasonably uniform degree of heat to bear on every tube.

Another typical boiler is the Heine. The tubes of this boiler all terminate in flat tube sheets, but these tube sheets are in such shape as to permit of proper staying. The water legs of this boiler are perhaps to some degree free to spread apart at the lower ends, but cases are not wanting where the tubes have been very much buckled by undue expansion. The course of the hot gases in this boiler is such as to heat the lower tubes much more than the upper ones, although, as with the Babcock & Wilcox type, the heat received by the tubes in each horizontal series is nearly equal. The greatest expansion is thus produced in those tubes that are least resisted by the plates of the tube sheets.

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CABLE RAILWAYS.

By JOHN WALKER, MEMBER OF THE CIVIL ENGINEERS' CLUB OF CLEVELAND.

[Read July 10, 1888.]

Since Mr. A. S. Hallidie put his first street cable railway in operation on Clay Street Hill road in the City of San Francisco, California, in August, 1873, this very interesting subject has had considerable attention, but not until late years has it had the attention it deserves. For nine years the benefits of this system were confined to San Francisco; since 1882 (in less than six years) Chicago, Ill., New York, N. Y., Kansas City, Mo., St. Louis, Mo., Cincinnati, O., Philadelphia, Pa., Los Angelos. Cal., Oakland, Cal., Omaha, Neb., Binghamton, N. Y., Grand Rapids, Mich., Hoboken, N. J., Peoria, Ill., St. Paul, Minn., London, Eng., Birmingham, Eng., Melbourne and Sydney, Australia, and also New Zealand, have availed themselves of this ideal method of transit, and many more cities are now obtaining franchises and contracting for road material and machinery.

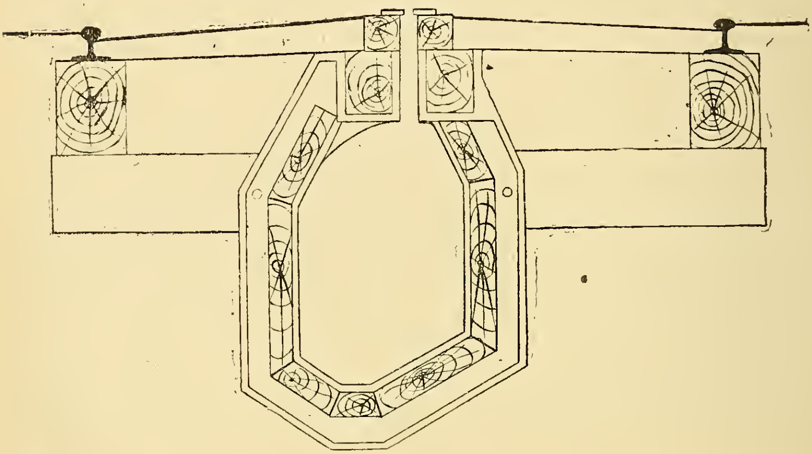
It is not necessary for me at this time to enter into the history of cable railways, the subject being of so recent origin and well ventilated in our public journals; something, however, may be said of the construction, operation and maintenance of these roads, to which points I will confine myself this evening.

Under construction we may speak of roadbeds, driving machinery, grips, cable and cars. The introduction of cable railways meant an introduction of another branch of engineering, in which both civil and mechanical talent were necessary; the problems and difficulties have been met from time to time, and solved generally in a very satisfactory manner. The roadbed is usually built with yokes 4 feet 0 inch centres, to which is attached the track rails at the outer ends, and the slot rails at the centre. These yokes have been made of different designs, all with a view to strength and rigidity to maintain the roadbed in proper align-

ment, and prevent the slot from closing. Some of these yokes have failed in both particulars, others have been successful. Fig. 1 represents the yoke which was used on the Clay Street Hill road in San Francisco by Mr. Hallidie: they were of cast iron, placed about 3 feet apart, and flanged to receive 2-inch planks, which formed the conduit. Five years later this yoke was substituted by one shown in Fig. 2, also of cast iron, and thoroughly bedded in concrete, the entire conduit being formed of the same material. The Sutter Street road as first constructed had a similar yoke to that used by the Clay Street Hill road, see Fig. 1 ; but afterwards the yokes were made of old rails bent into form as shown in Fig. 3, with horizontal "T" iron and braces to support the slot rail.

The California Street road, also of San Francisco, adopted this yoke, built in concrete, the tube being formed of the same material. The

Fig. 1.



Market Street road also adopted a yoke made of old rails, but modified somewhat in form; the conduit of the road was also made of concrete.

Fig. 4 represents yoke of cast iron as used by the Kansas City Cable Railway Co.; it is bedded in concrete, and the conduit is made of the same material, which seems to give good results.

Fig. 5 represents yoke of cast iron, as used by the Metropolitan Street Railway Co., of Kansas City; it has a depth of 8 inches at centre, also thickened at same place; it also has adjustable malleable iron brackets to support and adjust the slot rails.

Fig. 6 represents yoke of cast iron now being used in Denver, Col., by Mr. Harry M. Lane, for the Denver Tramway Co., it is 12 inches deep at bottom, and from several tests made at Watertown, it seems to possess special rigidity to prevent the slot from closing.

Reviewing the various forms of yokes shown, it will be seen that Figs. 1 and 3 have practically no strength at the bottom to prevent slot

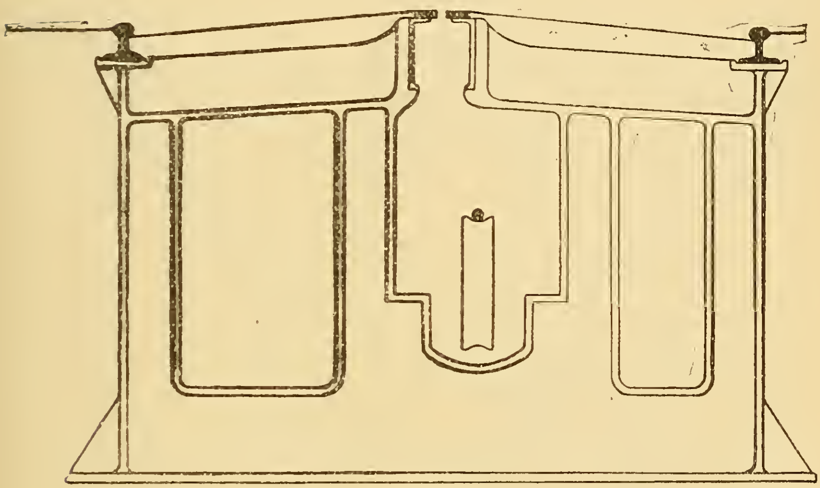
from closing. Figs. 2, 4, 5 and 6 are all improvements in that direction and have been doing good service.

Ordinary rails, side bearing rails, and the Johnson centre bearing rail have all been used on cable railways, the latter possessing advantages that none of the other sections have.

Slot rails are quite varied in section to suit the peculiar form of conduit and yoke and method of adjusting slot when such provisions are made.

It is preferable to fill between the paving stones between slot and track rail with pitch or some other water proof cement to prevent ice from forming and forcing the stones and thus closing the slot. I am convinced

Fig. 2.



that there has been more slot closing from neglect to fill between the paving stones in track than from any other cause.

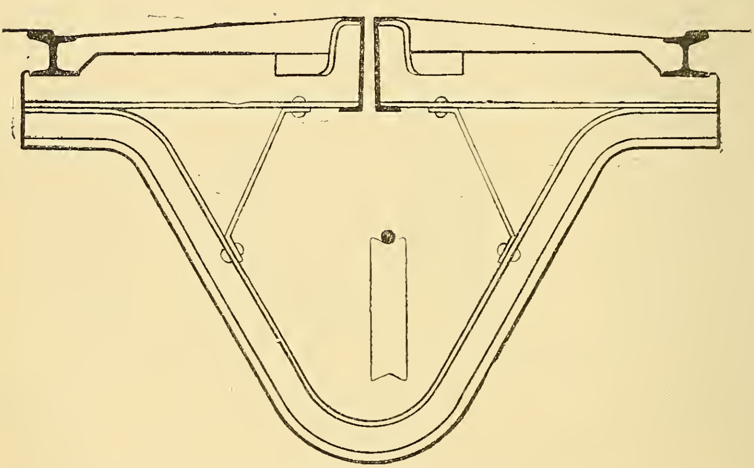
A cable railroad bed must be well made; cheap cement and concrete work has proven dear in the end; when properly made with proper yokes, slot and track rails, the alignment can be preserved indefinitely, when rail after rail has been worn away.

In connection with roadbed I may speak of carrying and curve pulleys, although they are a part of the mechanical work of a cable railway. Fig. 7* represents a carrier pulley, much in form and size as usually adopted; they are generally placed on every eighth yoke, each yoke being four feet centres, makes the carrying pulleys about 32 feet apart. There are many devices and methods for making these pulleys noiseless, and lubricating their bearings automatically; babbitt has been cast in a groove around the pulley to prevent noise and wear on cable;

* Not reproduced.

I scarcely need say that the babbitt wore away soon, and the sheave was useless until renewed again, which would cost as much as a new iron pulley; soft iron pulleys also wear away very fast. There seems to be no alternative for those pulleys but to chill them for service and deaden the noise in some way. One plan has been to secure the pulley frame in the concrete between the yokes so that it has no connection with the metals of the road ; this, however, does not prevent the inherent troubles of these pulleys making noise while in motion. The pulley shown here has been fairly successful in this particular ; it is cast with three arms to relieve strain, and in two halves with continuous chills to prevent cross fins in chilling, which in the ordinary pulley are seldom ground off and often nick the cable in their revolutions thousands of times in a

Fig. 3.



day. The two halves forming pulley are secured together by threaded screws in both pieces, and riveted with cardboard in between them to deaden the noise.

The box has a grease cup bored out with a neatly fitting plug with a cover to keep dirt from same. The plug and cover form a weight to press grease to a small hole in cup, through using a grease of proper consistency, to press same to bearing as required. These grease cups have lasted several weeks with one filling. In the ordinary way of oiling a cable road it takes four men and an oil refinery to keep them going.

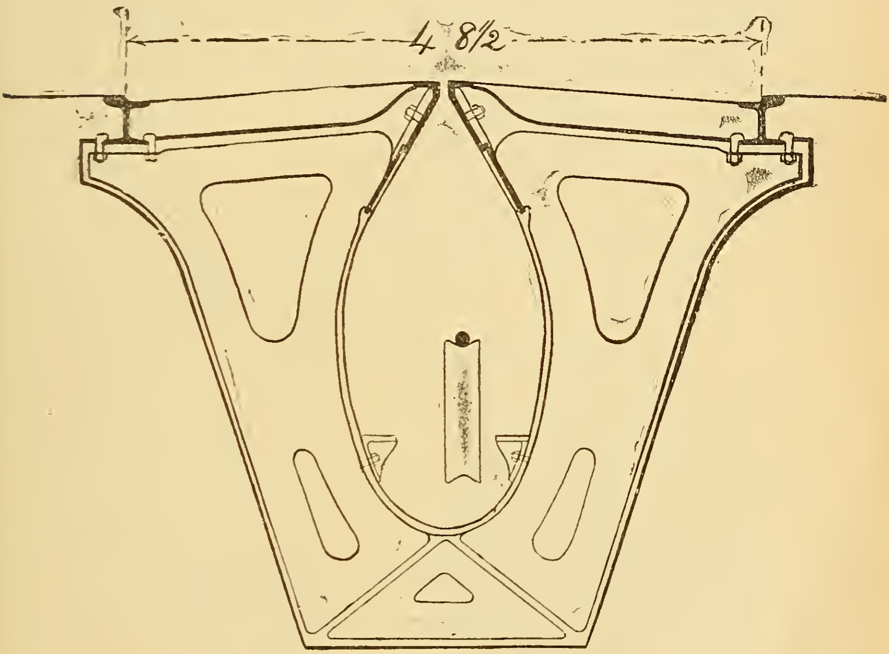
Curve pulleys have been made from 13 to 36 inches in diameter; their number and distance from centre to centre in a curve will depend entirely on their size. It is needless to say that curve pulleys too small in diameter need much attention, oiling and renewing boxes on account of their high speed.

It has been, and I believe still is, the prevailing custom to provide

these pulleys with a bottom flange (see Fig. 8) to support the cable in passing around the curve. As the cable rests on this flange and presses toward body of pulley, it is not long before the flange begins to chafe the cable severely. (See Fig. 9.)

To obviate this the Metropolitan Street Railway Company, of Kansas City, introduced a curve pulley without flange, and supported the cable on carrier pulleys placed between the curve pulleys at intervals around the curve. (See Figs. 10 and 11.) This system seems to be quite successful. and certainly dispenses with the chafing and destruction of the cable in the manner spoken of. This company had occasion to construct a curve

Fig. 4.



on a grade, and found that after the descending car passed the curve it would invariably leave the cable in an elevated and dangerous position. To obviate this, three curve pulleys of same size and shape as the others were provided, with a spiral groove terminating in the regular parallel groove. This spiral, with the revolutions of the pulley, lowers the cable gradually to its regular position without the slightest chafing or injury to the cable.

In connection with road-beds, I might introduce end pits, crossings, "let go" and "pick up" pulleys, depression pulleys, etc., etc., but time will prevent me to-night.

We now proceed to machinery and motive power. In these particulars

Fig. 5.

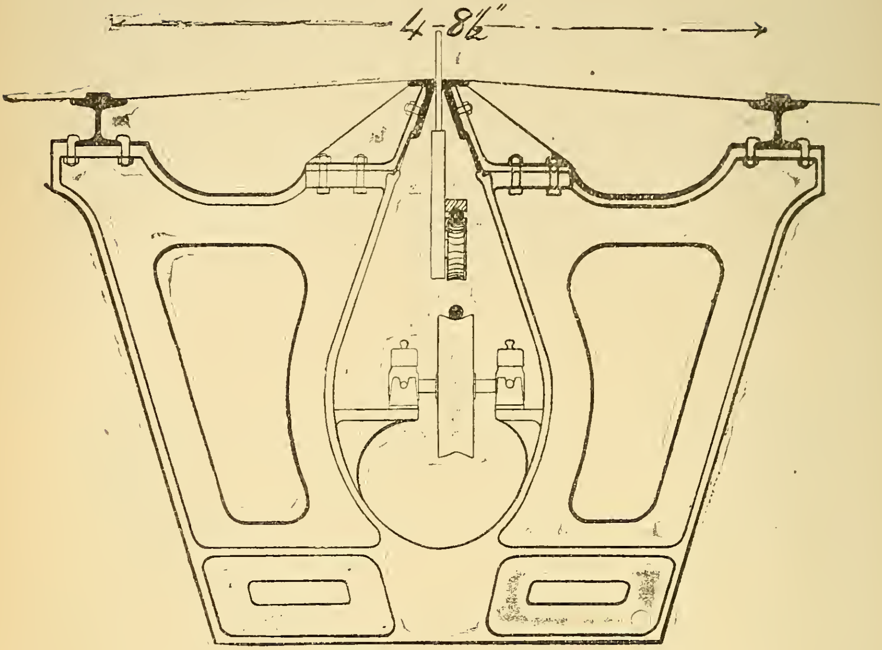
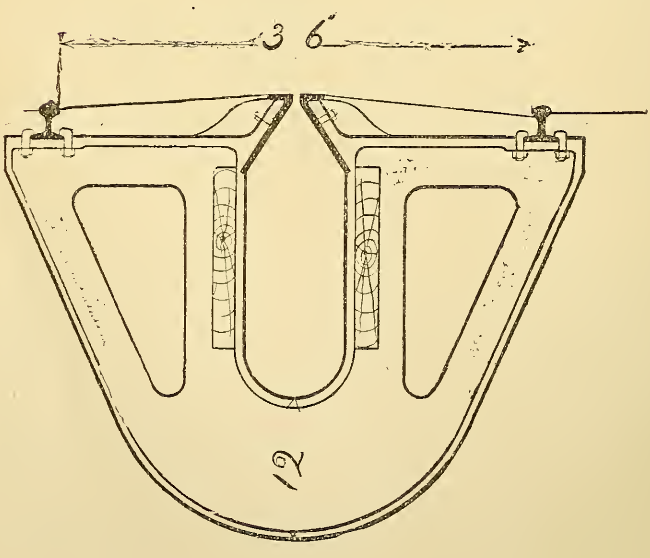


Fig. 6.



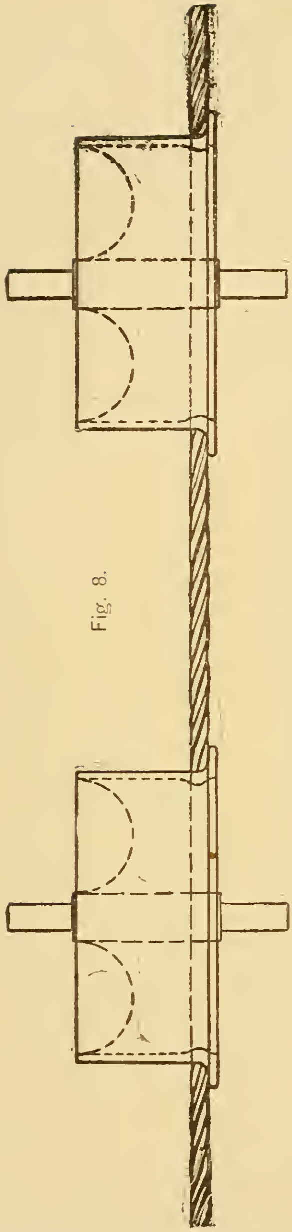


Fig. 8.

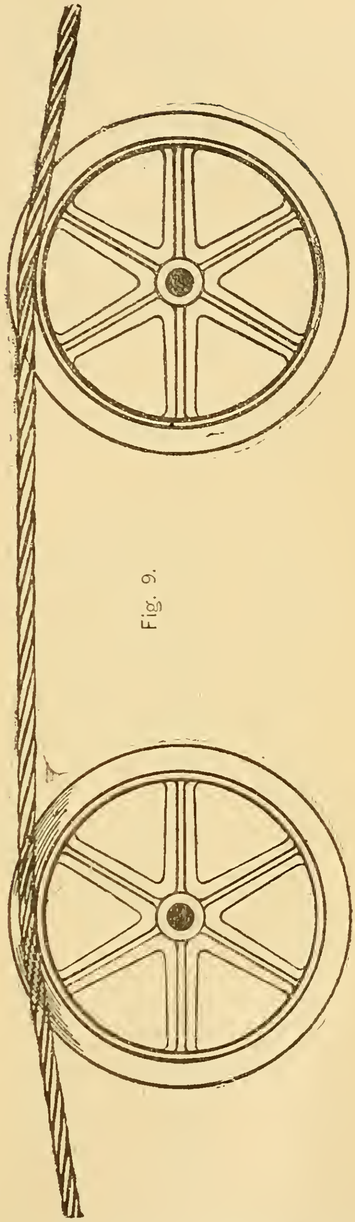


Fig. 9.

the demands of cable railways have caused more radical changes than in any other part of the equipment. Since Hallidie built the Clay street hill road, using an engine 14 inches by 28 inches, we find a gradual and steady increase of power needed, until at present we have plants of 1,000 and 1,500 H. P., with 28 inch by 60 inch and 30 inch by 72 inch engines.

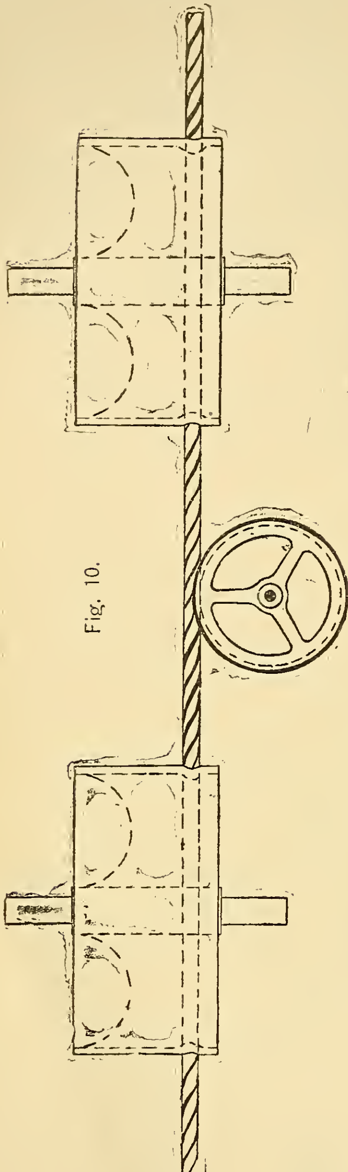


Fig. 10.

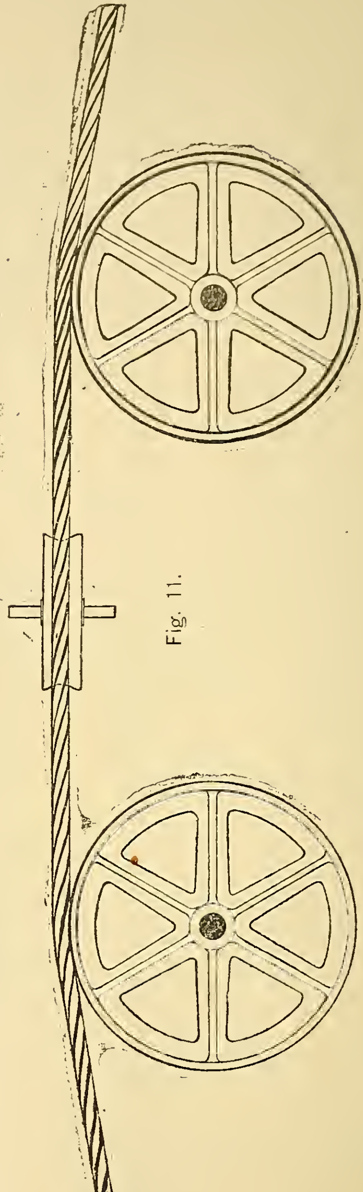


Fig. 11.

It is worthy of note that the fly-wheel of the St. Louis Cable & Western Railway Company's new plant in St. Louis, just completed, is heavier than the entire plant of the Clay Street Hill road, where cars weighing 2,800 pounds, and grip cars weighing 2,850 pounds, and seating fourteen and sixteen persons respectively, and seven such trains was the capacity

of the road ; we are now hauling cars weighing 8,000 to 9,000 pounds, and grip cars weighing 5,000 to 6,000 pounds, seating respectively forty and twenty-two persons, and running sixteen to twenty-six trains made

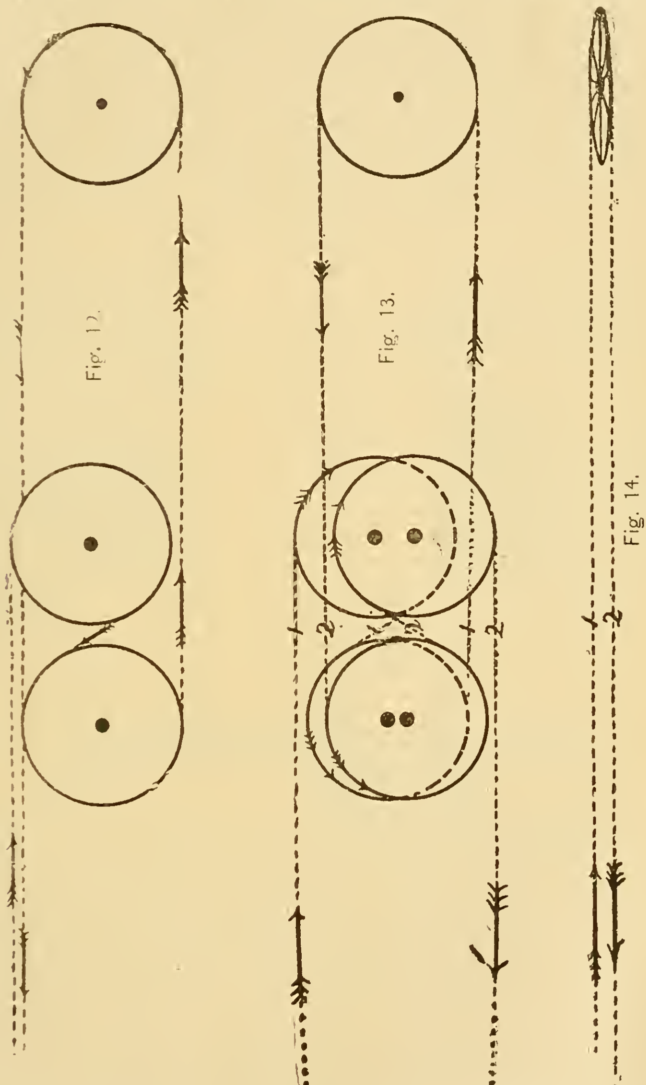


Fig. 12. Fig. 13. Fig. 14.

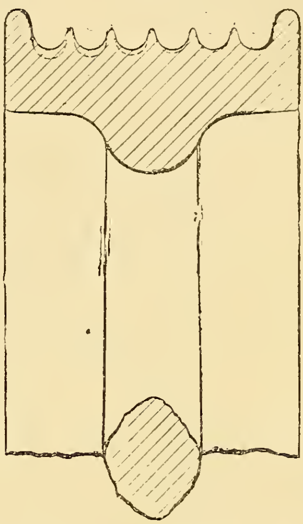
up of these cars and grips. This comparison will give you some idea of the increased demand on engines and machinery. The engines used in cable railway plants are almost exclusively of the Corliss type, this class of engine being well adapted for a variable load, such as is only known in the operation of cable machinery.

An indispensable adjunct to the engines is a heavy fly wheel. which very much lessens the jerking of the cars.

There are many different plans and arrangements of machinery for propelling the cable. The Clay Street Hill road, and Union Street, or Ferries road, San Francisco, used drums with clips inserted in such manner that the greater the strain the greater the clip would compress the cable; these drums had single grooves, and no doubt answered well for a limited length of cable, and a limited number of trains.

The Sutter Street road, of San Francisco, used drums with grooves made of wood inserted into a regular iron rim, and in connection with same used what is known as the figure 8 method (See Fig. 12.) The method is known as the figure 8, although the wrap only makes a par-

H Fig. 15.



tial form of that figure, this arrangement of machinery and cable having only one wrap, and not being able to make any more without chafing the cable, has the disadvantage of having to cut the cable to take it up after tension carriage has run the length of its track. Some time ago I had occasion to investigate this figure 8 system, and discovered that it was possible to get two partial figure 8 wraps on same pair of drums. (See Fig. 13.) The lines of cable marked 1, 1. 1, and 2, 2, 2, respectively, are directly over one another, as shown in Fig. 14, with tension carriage sheave tilted; the lines 1, 1, 1, and 2, 2, 2, respectively, occupy corresponding grooves on each drum; while this would be very desirable in driving, we are still unable to take up cable without cutting and splicing the same shorter.

The Geary Street road was the first to use a drum with a number of grooves cut in the solid metal (see Fig. 15), and rely on the friction or tractive power of the cable in the grooves, the wraps being made to suit the requirements of the road ; this is the kind of drum that has been

commonly used since. Experience, however, has developed the fact that these drums gradually become defective on account of wear in the grooves, and with two to three years' service must be renewed or the grooves re-turned to proper sizes; in the meantime, the gradual wear of the grooves has made a very perceptible difference in their circumference, and consequently a corresponding slippage of the cable in the groove and a very unequal tension of the cable while on the drum absorbing a great amount of power. The writer was never more convinced of this fact than when paying a visit to the Ninth street power station of the Kansas City Railway, Kansas City, Mo., when the friction of the cable from inequality of grooves became so great as to rasp the groove

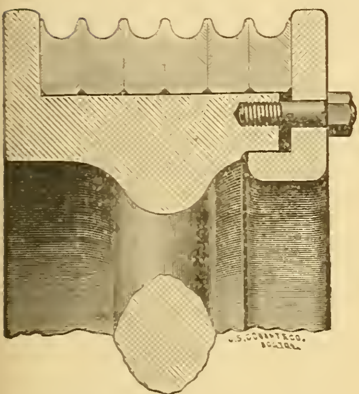


Fig. 17.

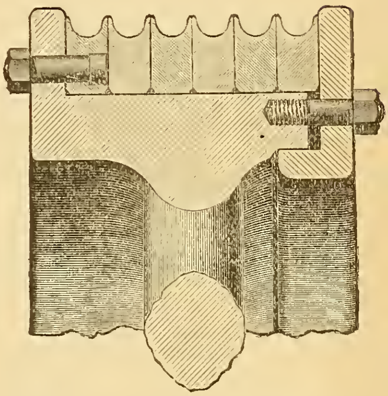


Fig. 16.

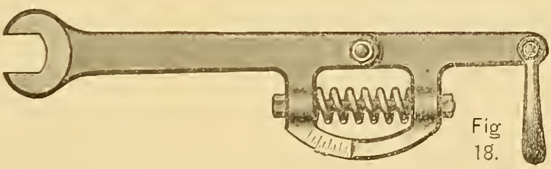


Fig 18.

as with an immense file, sending sparks of heated iron in the form of fire; this caused the drum to break in two between the arms.

Some time prior to this I had devised the differential drum shown in Figs. 16 and 17, which seems to meet all the difficulties found in the solid drum.

Fig. 16 is a section of the leading or driving drum; it is accurately turned to receive six wrought iron rings, one of which is secured to rim of drum, and the other five rings are all loose to move; the drum is provided with a loose flange, held in place and adjusted sidewise with studs to friction rings to the desired amount of driving we wish to do. This tightening is accomplished by a self-registering wrench, see Fig. 18, which makes a very simple and intelligent method of adjusting the required amount of friction, at the same time getting the friction

equal around the entire circumference. A pull of 120 pounds on the wrench on 1 inch studs will clamp the rings so tight that the cable will not move them; that is, the cable will slip in the grooves before it will move the

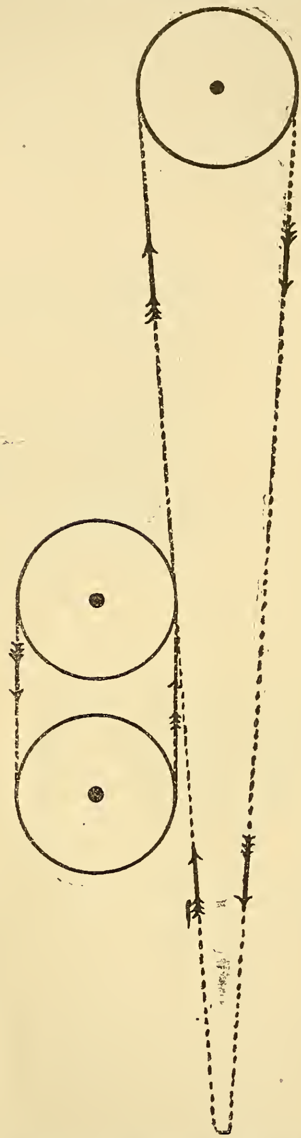


Fig. 19.

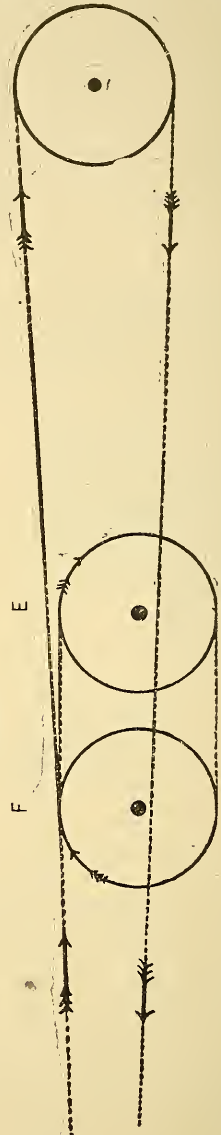


Fig. 20.

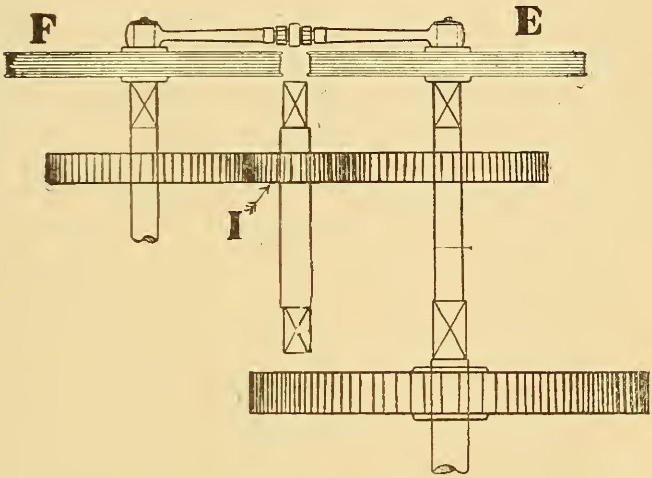
rings; from 30 pounds to 60 pounds on the wrench will give sufficient friction to drive and yet allow the cable to adjust the rings automatically without injury to itself. There are two practical ways of knowing when

the rings are adjusting themselves; first, the impression of cable will be left in the tar in the bottom of grooves, showing no slippage of cable; second, there will be no trembling of any of the wraps while passing from one drum to the other; they will all be tight and resemble bars of iron.

In no case is it necessary for the frictional driving on each ring to exceed $\frac{1}{10}$ of the strength of the cable, hence it is easily understood that the cable cannot be unduly strained while on the adjustable rings.

In practice we find that the rings do their work and move or adjust admirably under the conditions just named; it is questionable, however, as to whether side friction is needed at all as the diametrical fric-

Fig. 21.



tion of the cable in the groove is transferred to the bottom of the ring, which decreases or increases with the load.

Fig. 17 is a section of end drum, exactly the same as the leading drum, with the exception that all the rings are loose. By this system of loose rings it will be seen that the drums are differential in their relation to each other; also that the rings on each drum are differential to one another. With this arrangement it will be understood that when the cable is wrapped from one drum to the other it will be impossible to have any undue strain on any of the wraps; in fact, the cable will not commence to pull the load until each wrap has its portion of the load, thus equalizing the strain on the wraps, a feature impossible to accomplish on a drum with solid grooves.

The manner of applying cable to this class of drum is shown in Fig. 19, when circumstances admit of machinery being placed above street level, and tension carriage being placed below machinery floor. If it is

desirable to place machinery in a basement, and tension carriage on machinery floor, then by placing the drums below, the cable will occupy positions as shown in Fig. 20.

Now by proper winding of the cable on the rings we get two continuous wraps, and when the cable is tensioned with the load the friction with the fixed ring will propel the cable; at the same time the loose rings will adjust themselves to any undue tension or any inequality in their diameters.

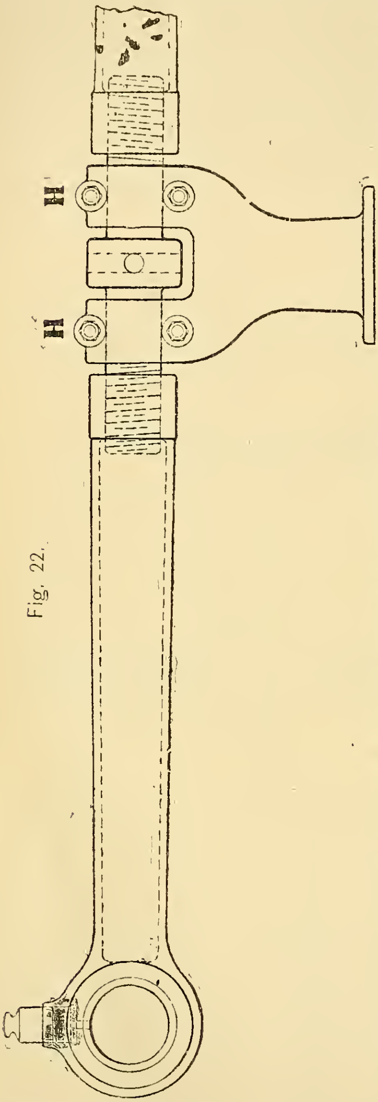


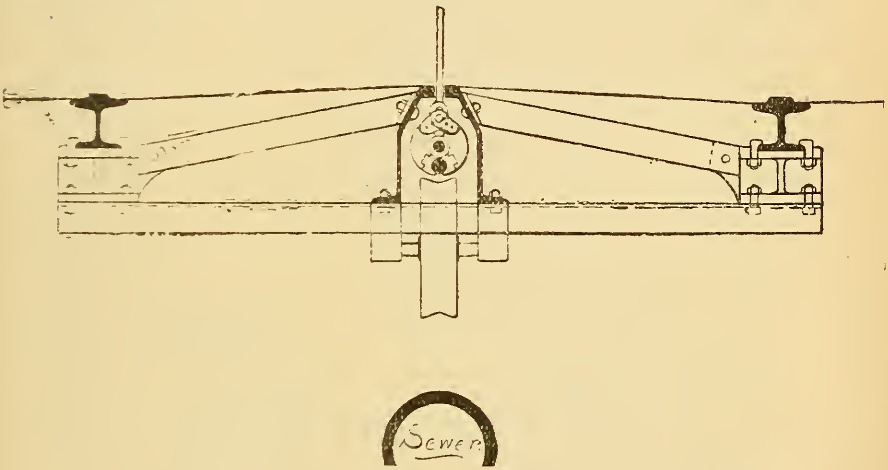
Fig. 22.

It has been customary in this class of plant with solid drums to drive the end drum *F* with gearing from the main line shaft, see Fig. 21, to get the tractive power of the cable in the end drum grooves; this is a very desirable arrangement if it were possible to make and keep the grooves in solid drums exactly the same diameter. The experience just recited shows that if the grooves were made practically the same diameter, it is not long before they wear to different diameters, as shown by dotted line on Fig. 15, the greatest wear being at the incoming groove, and gradually lessening in each groove used. It will be obvious that when these grooves are worn, there will be undue tension and slippage of the cable in the grooves to the extent of that wear, so that it is fair to presume that when the first or incoming groove *H*, Fig. 15, is worn one-fourth of an inch less in diameter than its neighbor, there will be a difference of three-fourths of an inch in circumference; this difference can only be accommodated by the cable slipping three-fourths of an inch every revolution on the groove already too small, or stretching the cable that much.

It would be impossible to stretch the cable three-fourths of an inch every revolution of the drum, hence we are driven to the more feasible conclusion that the greater part of this difference is taken up by the rope being propelled forward on the smaller groove, ab-

sorbing a considerable amount of power. It will be apparent that the more these grooves wear the more they will wear, since the difference in diameters increases as the wear continues ; now when the drums are worn, as explained, and they are geared together, it will be obvious that there will be a confliction between the positive drive of the gears and the cable when on different diameter grooves. A test of horse-power was made at the Fifth Street Power House, Kansas City, Mo., some time ago, the engines being indicated prior to removing the intermediate pinion *I* connecting drum gears, and then indicating after pinion had been removed ; the road being under similar conditions at each test, a saving of 35 horse-power was shown when the pinion was left out. The drums had been in use eighteen months, and would therefore be worn; had the drums

Fig. 25.



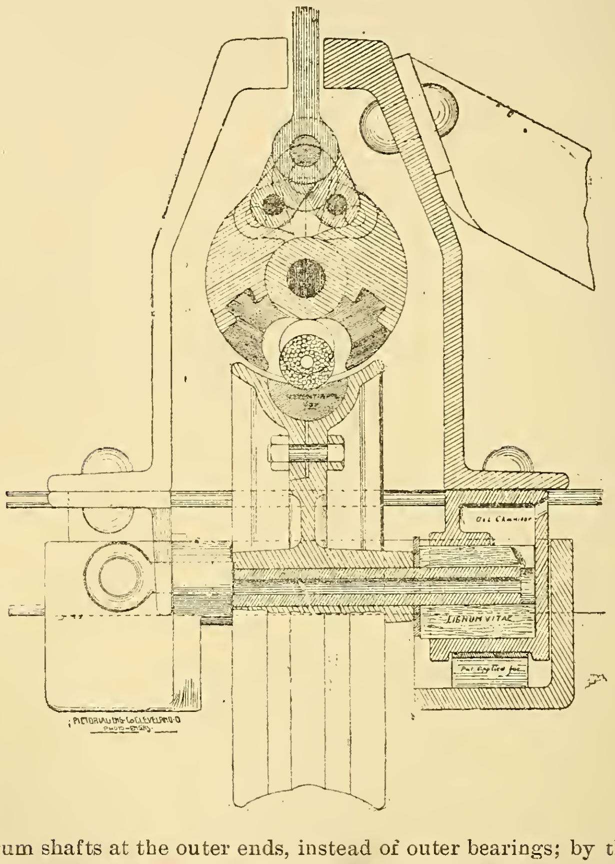
been perfect when second test was made there is no doubt but that a greater difference than 35 horse-power would have been shown.

The Grand Avenue Railway Company, of Kansas City, wisely left off the drum gears as the best solution in the use of solid drums. Other plants have been built since without drum gears at all; this, however, in my opinion, is a very questionable method of driving a cable. As the cable is by far the most severely taxed member of a cable road, it is in my mind the best policy to relieve it of some of its enormous duty instead of taxing it to drive the end drum or idler, as it is called, when not geared. The mere revolving of an end drum and its shaft would not be much, but when we add to this the enormous friction caused by the wraps of cable on the drums we certainly are taxing the cable unmercifully and unnecessarily; this, however, is not the only fault, for since the end drum is not driven it requires just as many more wraps on the leading drum to accomplish the same work. I think it will be apparent to all that with the differential drums geared together and with no

confliction between the gears and cable, but an automatic adjustable movement of the rings carrying the cable, that it will only be necessary to use half the amount of wraps when compared with the method of driving end drum with cable, for in the one case the cable drives the end drum, and in the other the end drum is used to drive the cable.

The strut, as it is commonly called, see Fig. 22, is an essential feature in cable plants using the loop system; it affords support between the

Fig. 26.



two drum shafts at the outer ends, instead of outer bearings; by this arrangement the cable can be taken up without cutting after the tension carriage has run the length of its track. Heretofore these struts have been made to adjust lengthwise with a taper key ; the strut shown has a right and left screw operated by a lever and the adjustment can be felt to a nicety; after adjustment the bolts *H H* are tightened on the screw to secure same from turning.

Grips have always been a conundrum in cable railroads as well as in "lodges." In cable railways, however, there are only two kind, a

"bottom grip" and a "side grip," the former taking the cable from below and the latter taking the cable from the side.

In the construction of a road it is necessary to decide what kind of a grip will be most suited, each grip having its peculiar advantages. Where many crossings have to be made under existing cables, the bottom grip seems to have some advantages in dispensing with reflections in the rails, etc. Root side grip is extensively used.

To describe the various grips would occupy too much time; however, in a general way, a grip has a lever coming through the car, convenient to the operator; it is usually coupled to compound levers or toggle movement to operate the jaws, which are closed or opened at will. A sector with teeth and pawl is provided to hold the lever in place when grip is secured to cable. The grip can be adjusted to run car at the same speed as cable, or at a less speed when occasion may require. Removable dies are placed in the jaws of grip; they have been made of almost every known metal, and even wood has been tried for grip dies. The softest dies I have seen were made of copper; the hardest were of tool steel hardened. There is no doubt but that this latter material will do good service if the dies are not too expensive to make. Hard bronze has been giving good satisfaction, both in service and on cables; these are not as expensive as at first supposed; they can be bought for eighteen cents (18c.) per pound, and credited when returned worn at twelve cents (12c.) per pound, leaving a difference of six cents (6c.) per pound on the weight of the old dies, and 18c. a pound for the amount worn off, which is about one and a half pounds, making a total expense of 95c. These dies usually last a week to ten days.

Fig. 25 is a section of Vogle & Whelan's shallow conduit cable roadbed This is undoubtedly the smallest conduit that has ever been devised. It is about 9 inches deep and 6 inches wide inside, and formed of a special section of rolled iron. The sleepers are preferably of iron; the rails are supported on chairs to bring them to the proper height; the conduit iron is held securely to chair to prevent slot closing. The carrier pulley is secured to conduit iron, thus preserving a regular depth and alignment, and is accessible through manholes between slot and rail. The manholes are connected from one to another by a sewer at the bottom, thus keeping the cable freer from refuse and grit than when a a large conduit is used for the cable and to act as a sewer at the same time.

This small conduit has been made possible by Mr. Vogle's ingenious bottom grip, fig. 26. The body of the grip is round, with spherical ends shaped to throw off a strand. The small levers hinged to the rotating parts of body form a powerful toggle joint. The dies are inserted in dovetail slots, and held in place by the spherical end caps. The grip body runs within half an inch of the carrying sheave, and cable can be taken as easily over a carrying sheave as between carrying sheaves. The depressing frame to which the grip is attached is supported on grip-car with springs to carry its weight, and can be depressed three or four inches in descending for the cable, but as the deflection of cable between carrier pulleys seldom exceeds one inch, the operator has but little trouble in getting the cable.

I understand that a road of this kind has been built in Tacoma, W. T., and arrangements are being made to build others. The figure shown is the all iron construction, and can be built for $30,000 per mile and $10 per foot extra for curves. A wooden construction for suburban roads can be built for $20,000 per mile. These figures compare favorably with the regular deep-conduit system, which costs from $80,000 to $100,000 per mile and $30 per foot extra for curves. Even with this enormous cost a cable road can be operated as economically as with horses with a traffic of 4,000 passengers daily ; and for every inccrease above this there is an increase of profits in favor of the cable road, as the operating expenses are not near as much in proportion as on horse car roads with a traffic exceeding 4,000. I inquired recently from the manager of a comparatively new cable road for the percentages of receipts for operating and maintenance of road. His answer was 70 per cent. of receipts for operating and 11 per cent. for maintenance; expenses will be but little more when travel is doubled.

It has been a noteworthy fact that a cable railroad has always improved property along its line, and especially so when it runs through suburban property. The projectors of cable railroads into suburban districts have been public benefactors, making it possible for business men and working men to live in the suburbs, and yet get to their places of business in quick time.

I trust that the time is at hand when Cleveland will come to the front with cable railroads running in every direction. Our streets are well adapted, the need is apparent, and we await a public benefactor.

DISCUSSION.

Mr. Holden : Does the $30,000 a mile you mention include power, or simply the construction of the road ?

Mr. Walker : That amount is for the construction of a mile of single track with necessary pulleys ; it does not include power plant.

Mr. Holden : What additional amount would be required for power on a four mile road, for instance ?

Mr. Walker: I think it would be about $25,000 to $30,000 a mile additional. This amount would be about the same whether the regular roadbed, or the Vogel and Whelan system was used.

Mr. Sargent : Is it not necessary to have a double-track road ?

Mr. Walker : Yes, sir ; I spoke of the single-track road with reference only to its cost.

Mr. Searles: The question of drums has been very interesting to me because the wearing of the grooves in the drum has been one of the greatest difficulties connected with the operation of cable roads. I am favorably impressed with these friction rings; it would seem as if they would obviate the difficulties arising from unequal diameters of grooves. The driving friction is on the sides of these rings, yet it occurs to me, nevertheless, that there will still be considerable friction between the rings and the solid drum, and that will tend to a loosening of the rings on the drum. I would like Mr. Walker to state if he has made provision for meeting that difficulty. When he first used the word "adjustable" I thought he referred to the adjustment of the diameters, but I see that

he means the amount of friction on the sides. If there is no break in the rings they will be loose on the drums, or with one they will close on the drums and be a little smaller in diameter. I think we shall not have a perfect working system till we can maintain uniform diameters.

Mr. Walker: I do not lay much stress on the side friction, I rely more on the diametrical friction. We will suppose that the rings are entirely free sidewise, we increase or decrease the diametrical friction with every car we put on or off, making the amount of friction, consequently the power, according to the resistance. Hence I believe the drum would drive without side friction; I prefer, however, a little side friction, but nothing like an amount that would damage the cable by preventing the rings from turning.

Mr. Holden: How do you know that the cable does not slide on the ring, as it does on the groove?

Mr. Walker: There are two ways of knowing when the cables are adjusting themselves with the rings. First, when the cable slips in the grooves of solid drums, the wraps that pass from one drum to another can be seen to vibrate: when the rings are adjusting themselves on differential drums, the cable, forming wraps from one drum to the other, resembles solid bars of iron. Second, when the cable slips in the grooves of solid drums the grooves will be smooth and bright. In the differential drums the cable leaves its imprint in the tar left in the groove of the ring.

I think these two features give evidence of the adjustability of the rings.

General Leggett: The friction of these rings on the drum tends to wear the inside of them. How is that remedied?

Mr. Walker: I do not anticipate more wear on the inside surface than on an ordinary bearing. Of course there will be some wear, but even if there is the rings will go on adjusting themselves and not damage the cable.

Mr. Whitelaw: Is it intended to renew the rings or the drum itself?

Mr. Walker: The rings would be the simplest and much the cheapest to renew.

Mr. Searles: If there was considerable wear after a time the rings would be partly separated from the drum; there would finally be a sort of inner rolling motion; in other words, there would not be complete contact around the semicircle.

Mr. Walker: This would, no doubt, be true if wear was excessive and the rings were rigid; their large diameter, however, will allow them to spring enough to obviate a rolling motion; they can never wear to that extent. I omitted to speak of the lubrication of these rings. There are five large grease cups that keep a constant lubrication; I have seen the grease work out between the rings while the drums were in motion.

Mr. Rawson: How much slipping have you observed?

Mr. Walker: In our first experiment at Twelfth street we made some small holes in the rings and inserted pins; with friction drawn up to 120 pounds on the wrench, we found there was no motion at all in the rings. We weakened the pull on wrench until we found where they would move. The rings would not always move in one direction, showing that

there is a good deal of stretch in the cable as it is wound on the drum. The rings sometimes go forward and sometimes backward ; some would actually reverse the motion again. That proved to me that the cable was wound on the drums with different tensions, and the rings responded to the varying resistance of the road.

We have found that a low side friction or pressure is best ; the wraps of cable passing from one drum to the other will be steadier and stiffer at 30 pounds on the wrench than at 60 pounds.

Mr. Searles: Is that road in Tacoma in operation with this new conduit?

Mr. Walker: I could not say. It was building three months ago, and on the wood sleeper plan. Mr. Vogle is a Californian, and is quite a cable engineer, and I have every faith in his work.

Mr. Searles: The difficulty is that the clearance is so small that the grip might touch the conduit with the jolting of the car.

Mr. Walker: Mr. Vogle has about one inch clearance in conduit at sides for his grip, whereas the shank of grip has only the usual clearance in slot. He dispenses with guard rails in passing round a curve, as the conduit iron where slot is formed is thickened to answer the purpose of a guard rail.

Mr. Searles: Is there no floor to that conduit?

Mr. Walker: There is no floor shown; it can be made of bricks, concrete, or an iron plate can be laid under conduit iron between ties. The water that goes into the slot passes into manholes at each carrier pulley, then to the sewer below

Mr. Searles: The conduit is about the same size as Johnson's.

Mr. Walker: I think it is; Mr. Johnson's I think is a little wider.

Mr. Searles: They both stand on top of the ties.

Mr. Walker: Yes, sir.

A Voice: What distance apart are the studs on driving drum?

Mr. Walker: About 1 foot 9 inches to 2 feet. There are 28 in a 16 foot, 24 in a 14 foot, and 20 in a 12 foot drum.

Mr. Whitelaw: Do they use a double flange wheel?

Mr. Walker : No, sir; that is simply for centre bearing on the rail, the ordinary wheel being used. I noticed in St. Louis with the side bearing rail they had filled under outer flange with wood; after a year or two of service it was no good, being rotten.

Mr. Searles : I found in the St. Louis old plant, when the engine was first started, there was great difficulty on account of unequal motion between the cable and the gears. The pinion in St. Louis was dispensed with; I should think there would be no necessity for dispensing with it with those adjustable rings, while there would be great advantage in in keeping it in.

Mr. Walker: I think it is only a question of time when cable engineers will adopt the differential drum and put gears in again.

Mr. Searles: Have you card records to tell what horse-power it takes to drive this machinery without the cars?

Mr. Walker : On the St. Louis & Western Railway it requires 185 horse-power to propel the cable alone at 8 miles per hour. There are slight grades varying from one to five per cent. There are 13 double curves on

the road, 26 in all: some of these curves are only 29 feet 6 inches radii, and consequently there is much loss of power in turning them. Twenty cars composed of grip car and regular cars; weighing 5,000 pounds and 8,500 respectively, passengers additicnal, would take from 180 horse-power to 190 horse-power, making 9 to 9½ horse-power per train. When this data was taken the road was under ordinary condition and traffic. The cable was 34,600 feet long and 1¼ inches diameter; this cable was the longest ever operated in one piece. Since new machinery has been supplied it has been made into two lengths. The Fifth street cable road, Kansas City, Mo., referred to in the paper, takes about 120 horse-power to propel the cables alone at eight miles per hour; the road had few curves and grades; the steepest, however, being about seven per cent. Twenty trains of grip car and regular car with passengers would indicate about 280 horse-power; deducting the 120 horse-power for propelling empty cable, would leave about 8 horse-power per train of grip and car. When President Cleveland was in Kansas City, the traffic was much increased; the engines indicated 484 horse-power for 22 trains, making 16 horse-power per train, allowing 120 horse-power for moving empty cable as before. It will be seen that there is more economy in horse-power in running the cable with heavy traffic than light, as the frictional resistance of the cable is not in proportion to the amount of traffic carried. The combined length of the two cables is about 40,000 feet.

Mr. Searles: What is the difference in power required to drive machinery between the ordinary solid drum and the drum supplied with these rings?

Mr. Walker: I have not got the data yet on this point. I think, however, that the illustration mentioned in the paper shows conclusively that there is great loss of power in running solid drums when they are worn.

Mr. Searles: As near as I can gather, the horse-power required to move machinery alone is about 11 horse-power per mile, modified, of course, by the curves.

Mr. Walker: Eleven horse-power may be sufficient for straight roads, but would not be sufficient for a road with many grades or curves; approximate estimates only can be made for the horse-power of cable railways, even from the most carefully prepared profiles. The engine indicator is the final source of evidence. There is one feature, however, in cable railways that generally escapes notice, that going up grades of 14 or even 20 per cent. is not so destructive to the cable as making right angle curves. This is contrary to the general impression, but is easily understood when the line of cable in curve is compared with line of excessive grade. The cable going up a grade of even 20 per cent. passes through no such contortion as in a curve. It is also very questionable whether the tensile strength of a cable is tested as much on a 20 per cent. grade as it is in a curve of say 40 feet radii.

Mr. Rawson: What devices have they for indicating loose strands?

Mr. Walker: There is what is called a strand indicator, a device electrically connected so that when any enlargement of the cable moves an arm it will ring the signal at the engineer's desk; it is placed on the incoming cable so that strand may be cut off or fixed before leaving the machinery room.

Mr. Rawson: May not a strand develop itself going out and travel seven or eight miles?

Mr. Walker: That might occur. There are signals along the road to announce to the engine man at once anything that happens on the road. The strand signal can be placed at the end of the road, if it is a switch terminal, as well as at the power house. A strand may be from 50 to 1,000 feet or more long, but they are generally cut off before much damage is done. A cable can run a long time without one strand without injury to the cable; at night they stop and put in the strand or whatever is required to repair the cable. They can put in about 1,000 feet of strand, or splice a cable, in about four hours.

Mr. Whitelaw: About what is the life of one of these cables?

Mr. Walker: The shortest I have known was about four days; the longest about eighteen months. They usually last from six to eighteen months.

Mr. Mordecai: How often would they have to stop for repairs with a good plant?

Mr. Walker: Sometimes they run four months without the slightest stoppage. The St. Louis Cable & Western road lately made a run of three months without stoppage; they had a mixed cable of three pieces, about 19,000 feet being new. I believe with our differential drums and new machinery the cables will last much longer than before.

Mr. Mordecai: What was the trouble in Market street, Philadelphia?

Mr. Walker: I think the principal trouble was the slot closing. The machinery was built by Wetherell, of Chester, Pa. He had an arrangement for a differential movement, but it is differential in one part only, it does not act on all the wraps.

Mr. Rawson: What provisions are now made for stoppages?

Mr. Walker: Some companies keep a few horses in stock, but repairs are made so quickly now that it is very rare to have any accident happen that cannot be put right in a few minutes.

Mr. Swasey: Mr. Hallidie said that with modern arrangements a cable could now stand about two years. One quite notable feature in using belts from the engine to the main driving shaft, Mr. Hallidie said, was that it was easier for the cars with the belt than with the gears, you felt less jar.

Mr. Walker: The life of a cable has been very much shortened by the attempt to run too long roads. Engineers seemed to try to outdo one another in the length of road. Thirty-four thousand six hundred feet was the length of the St. Louis Cable & Western Railway's. It was the longest cable in the world; it has now been cut in two. The length of the cable should not exceed 25,000 feet.

Mr. Searles: A straight line might be worked 35,000 feet, but the curves increase the difficulty.

Mr. Walker: The curves and grades must always be taken into consideration.

Mr. Rawson: How would you adjust that?

Mr. Walker: We built a new plant, which was double. We have about 10,000 feet of cable on one end and 24,600 feet on the other.

Mr. Searles: I saw a statement in a paper this week with regard to the

relative expense of cable, electric and horse cars. It was that the expense of an electric road being one, the expense of a horse railroad would be 1.47, and of a cable road about 1.65. An inversion of these figures would be nearer the truth.

Mr. Walker: Chicago has run cable cars at an expense of 11½ cents per mile, as compared with the old service of horse cars at 24 cents per mile.

FIELD-BOOKS.

By Edward Butts, Member of the Engineers' Club of Kansas City.
[Read March 5, 1888.]

In preparing a paper on the subject of field-books it seems proper to refer back to a time previous to the introduction of that special branch of engineering literature. In the thirteenth edition of a volume entitled "Geodæsia: or, the Art of Surveying," by John Love, printed in New York in 1796, we find the following of the field-book: "You must always have in readiness in the field a little book, in which fairly to insert your angles and lines, which book you may divide by lines into columns, as you shall think convenient in your practice, leaving always a large column to the right hand to put down what remarkable things you may meet with in your way, as ponds, brooks, mills, trees, or the like. You may choose whether you will have any lines or not, if you can write straight and in good order the figures directly one under another. For this I leave you chiefly to your own fancy, for I believe there are scarce two surveyors in England that have exactly the same method for their field notes."

In Hutton's "Mathematics," published in 1833, is the following of the field-book: "In surveying with the theodolite or any other instrument, some sort of a field-book must be used to write down in it a register or account of all that is done or occurs relative to the survey in hand. This book every one contrives and rules as he thinks fittest for himself. Some skillful surveyors now begin at the bottom of the page and write upward."

Worcester's Dictionary, published in 1883, contains the following: "Field-Book (*surveying*). A book used for setting down angles, stations, levels, etc."

Webster's Dictionary, published in 1886, contains the following definition: "Field-Book. A book used in surveying or civil engineering, in which are made entries of measurements taken in the field."

The word field-book does not appear in Walker's Dictionary in 1831, but the word pocket-book is said to mean "a paper book carried in the pocket for hasty notes." This definition of the pocket-book is also given in the latest edition of Worcester's and Webster's dictionaries, which accounts perhaps, to some extent, for the words field-book and pocket-book being often used indiscriminately.

By the foregoing it is obvious were we to rely upon our vocabularies for an understanding of what we term a field-book we would have a very meagre idea of the extent of the meaning of the word, as in addi-

tion to the aforesaid the word field-book means a small book containing formulæ and tables applicable to the location of railroads, principally devoted to the formation of curves. The formulæ and tabulated information contained in the field-book are deductions of geometrical principles established by mathematicians more than two thousand years ago, and were presented at that time by Euclid in a systematic form.

The first application of the method to lay out railroad curves by means of offsets from the tangents and chord is claimed by Mr. T. Baker, of England, who is said to have communicated the method, as early as 1824, to the *Gentleman's Diary* for insertion, but for given reasons it did not appear in that journal until 1837.

As to who first applied the method of laying out railroad curves by means of deflection angles, as practiced at present, Mr. S. H. Long is unquestionably entitled to the credit. His "Railroad Manual, or Brief Exposition of Principles and Deductions Applicable in Tracing the Route of a Railroad" was published in 1829. "The design of this little work," says the author, "is to place in the pocket of the engineer a brief and perspicuous compend of easy rules that may serve as a directory to guide him in tracing the route of a railroad."

This is the first book printed especially for field use. It is divided into two parts; part one containing one hundred and ten pages, of which fifty-one pages are descriptive of laying out various railroad curves as practiced in the United States at present; eleven pages on the subject of resistance to locomotion upon curved and inclined railroads, twenty pages on reconnoissance, twenty pages on earthwork, and eight pages on the elevation of the outer rails of curves. Part two contains sixty-two pages, all devoted to mathematical tables as follows: Sub-chords and angles for various radii, three pages; sub-chords, versed sines and deflections for distances of ten feet for a one degree curve to a fourteen degree and thirty minute curve inclusive, expressed for each thirty minutes of curvature, thirty-one pages; long chords, ten pages; distances around curves, four pages; turnouts, two pages; arcs, two pages; roots and squares, six pages; elevation of outer rails on curves, two pages; ordinates, two pages. It will be readily seen by the above contents that this book was very similar to the latest published field-books.

"Methods of Location or Modes of Describing and Adjusting Railway Curves and Tangents, as Practiced by the Engineers of Pennsylvania," is the title of the second field-book printed in the United States. It was written by Samuel W. Mifflin in 1837, the second edition of which appeared in 1850, and the third edition in 1854. This book contains forty-eight pages, all, except about four pages, are devoted to curve problems, the solutions of which are made by geometrical diagrams. The method for laying out curves is first to run in a curve and afterwards adjust it to the desired location, never intersecting the two tangents, as is generally the practice now. There is on the forty-eighth page a table of chords, which is the only mathematical table in the book. In the preface, Mr. Mifflin says: "In such a work I consider it of importance to dispense with all difficult calculations, and even with tabular statements which cannot be committed to memory. In this I have fortunately succeeded. There is nothing in the following pages which may not be remembered

by an assistant after a short practice, and executed in the field even if the book be left at home." This work was, no doubt, in its time an excellent addition to the civil engineer's appurtenance, as it has received the approbation of the best engineers of its day. It certainly contains nothing that could be considered superfluous, except, perhaps, the articles on the adjustment of instruments. To dispense with all tabular statements and compel the assistant to memorize all that is required in field practice would hardly apply to the professional advancement of 1854. The book is now out of press, its method of demonstrating problems in field-books having gone entirely into disuse. It is believed that this and Colonel Long's Railroad Manual are the only printed field-books that have gone out of press since the introduction of that branch of literature.

In 1846 there was printed in Berlin a book entitled "A Practical Manual for the Determination and Construction of Railroad Curves," written by B. Brunckow. In the preface of this book we find the statement that previous publications of this kind have been printed in pamphlet form containing tabulated calculations made for angles of whole degrees only. Also, the tables inserted in this volume, in addition to being much more extensive, are carried, in many cases, to four decimals, to give a more correct result in their use. This book is printed in both the German and the French languages. The base of all calculations contained in this volume is the Prussian ruthen, reducing the various measurements of fifty-three different European states to that equivalent, which forms Table A, occupying twenty-six pages, and consisting of five hundred and thirty computations. Table B occupies one hundred and ten pages, and consists of sixteen thousand and five hundred computations. These computations consist of tangents, arcs, the shortest distance from the curve to the point of intersection ; the shortest distance from the centre of the curve to a point on either tangent. Also, the distance from the last named points to the point of intersection. All calculations in this table are for a radius of one hundred ruthen for every alternate or even minute of angle from naught to one hundred and ten degrees. Table C occupies fifteen pages, and consists of distances from the tangents to the curve for every five feet along the tangents for various radii, from fifty to one thousand ruthen. There are in this table one thousand one hundred and sixty-seven computations. Table D gives that part of the tangent between the point of intersection and a point on the tangent perpendicular to the radius at the centre of the curve. This table covers thirty-six pages and consists of three thousand three hundred computations. Table E consists of half the chord from the point of curve to the point of tangent, also the perpendicular distance from this chord to the radial point, calculated for a radius of one hundred ruthen for every alternate minute of angle from naught to one hundred and ten degrees. Fifty-five pages are devoted to this table, which contains six thousand six hundred computations. Table E plus consists of ordinates for every five feet for various radii from fifty to one thousand ruthen. This table covers fifteen pages, and is composed of one thousand one hundred and seventy-three computations. The whole volume is composed of two hundred and seventy-seven pages, which contain

twenty-seven thousand nine hundred and three computations, devoted exclusively to the wants of the locating engineer. This book may well be considered a remarkable production when the date of its publication is considered. It also is remarkable for its treatment of the special subject, *i. e.*, the location of railroads, which is rare for Europe.

The method of laying out curves with offsets and ordinates was the first method to suggest itself to the civil engineer. This practice has long since gone out of use in the United States, having been superseded by the method of measuring and deflecting around the curve. This has also been generally adopted throughout Europe, though the first method is still to some extent in use.

The first edition of the "Engineer's, Contractor's and Surveyor's Pocket Table Book," by J. M. Scribner, appeared in 1847 and the twelfth and last edition in 1887. This book is intended for a "field or office" book. It contains the logarithms of numbers, also logarithmic sines and tangents, the traverse table, table of natural sines for each five minutes, also the same for natural tangents, table of segments of arcs, and the length of circular arcs, explanation of the prismodial formula, table of excavation and embankment, consisting of eleven tables. Some of these tables are made out for stations sixty-six feet apart, with cuts given in feet and inches; others are made out for stations sixty-six feet apart, with cuts given in feet and tenths, and others are made out for stations one hundred feet apart, with cuts given in feet and tenths. These are followed by tables of arcs of circles, square and cube roots, weight of iron bars, weight of cast-iron pipes, strength of material, etc., etc. "Hints about laying out curves—in laying out curves," says the author, "the following method has the advantage of great accuracy and expedition over that of angles taken by an instrument." The method given is to use chords and offsets calculated in an approximate way. Perhaps in 1847 Mr. Scribner could lay out curves by this method with more accuracy and expedition than by the other method he speaks of, but it cannot be done in 1887.

Hints on curves is followed by tables for ascertaining the superficial quantity of land for railroads and canals, diagrams and explanations of earthwork in canals, tables of board measure, etc., etc., closing the volume with eighteen pages of advertisements. The table of logarithms is about all that this book contains that can be made serviceable to the civil engineer as a field-book.

In 1851 the first edition of the "Field Practice of Laying Out Circular Curves for Railroads," by John C. Trautwine, was published. This book contained seventy-five pages, devoted exclusively to curves, except one page, which gives rules for adjusting the transit instrument. The table of radii, table of ordinates, table of long chords, and the table of natural sines and tangents, comprise the tables found in this book. The table of radii appears the first time in a field-book here; also the method of calculating the various curve problems by means of natural functions. In this volume there are twenty-two pages devoted to about the same number of curve problems. The sixth edition of this work, published in 1869, is the same as the first edition, except it has a few more curve problems, a table of middle ordinates for various lengths of rails, ten pages devoted to the resistance of curves, a table of

actual tangents for a one degree curve, calculated to the nearest foot for each ten minutes from naught to one hundred and twenty degrees. In reference to this table the author remarks: "For the following idea and table we are indebted to Mr. N. F. Jones, Civil Engineer." The principle by which this table is used was given in Mr. Brunckow's Field-Book in 1846.

A table of actual tangents for a 1-degree curve calculated to two decimals, for every minute from 0 to 90 degrees, with instructions to use just as Mr. Trautwine describes in 1869 and 1887 was printed in Mr. Cross's field-book in 1855. The thirteenth and last edition of this book, issued in 1887 contains 192 pages, being nearly twice the number of the preceding editions. There has been added about twenty-five more curve problems, a table of versed sines, 13 pages devoted to the engineer's transit, table of the elevation of outer rails on curves, an article on equation of curvature.

The reason for leaving out all frog or turn-out problems or tables may be explained by the following extract from the preface: "The number of problems might be indefinitely increased by the aid of Euclid or of any good modern work on geometry, but in fact very few are required in actual practice. Any extraordinary ones that may present themselves can be solved by drawing. In preparing his drawing for this purpose the young assistant need not always confine himself to such scales as may be managed by the common dividers, but when, as often happens, only a few chains of a curve need be drawn including turnouts, etc. He may with great ease lay them off on the same principle as in field operations by using his protractor, and either by long chords or by tangential and deflection distances and angles employing a scale of three to twelve, etc., inches to a hundred feet, and filling in the intrevals when required by the table of ordinates. Even when the preliminaries of a curve have been found by calculation it generally has to be run two or three times on the ground before it will fit perfectly. Therefore. a resort to a drawing does not necessarily increase the field work." The name "Table of Actual Tangents," given in previous editions, has been changed to "Table of Actual Apex Distances" in this. The articles on the transit, the elevation of the outer rail on curves, also the articles on the resistance of curves and equation of curvature might be termed superfluous matter for the field-book.

The first edition of John B. Henck's "Field-Book for Railroad Engineers" was published early in the year of 1854. The following is an abstract from the preface: "The object of the present work is to supply a want very generally felt by assistant engineers on railroads. Books of convenient form for use in the field, containing the ordinary logarithmic tables, are common enough, but a book combining with these tables others peculiar to railroad work, and especially the necessary formulæ for laying out curves, turnouts, crossings, etc., is yet a desideratum." This is the first printed book that contains the word field-book in its title. Also, here we first find the term tangent applied to the distance between the point of intersection and the point of curve. That which Mifflin and Mr. Trautwine has previously termed in their field-books the tangential angle is here known as

the deflection angle, which is equal to one-half of Mr. Trautwine's deflection angle. This book contains about sixty problems relative to curves, embracing circular curves, reverse curves, compound curves, parabolic curves and turnouts, occupying seventy-seven pages. There are twelve pages devoted to leveling and twenty-three pages devoted to earth work. Followed by tables of radii, long chords, frog angles, properties of materials, magnetic variations, trigonometrical formulæ, square and cube roots, logarithms of numbers, sines and tangents, natural sines and tangents and various grades per mile, making in all two hundred and forty-three pages. The book retained its original form until 1882, when an appendix of twenty pages relative to curves, levels and rail expansion was added, also a table of "tangents and shortest distances from intersection point of a one-degree curve," calculated for each five minutes from one to ninety degrees. The table of properties of materials and the table of magnetic variations have been left out of the last edition, the space they occupied being filled with tables for computing heights by the aneroid barometer. This exchange is generally considered injudicious, speaking specially in reference to the table of magnetic variations. There are forty pages of this book devoted to leveling and earth work, which are an unnecessary appendage to a field-book. Also it is unnecessary for a field-book to contain both the tables of logarithms and natural functions, the former being rarely used, when the latter is obtainable, by the older field engineers.

The first edition of the "Railroad Engineer's Pocket Companion for the Field," by W. Griswold, appeared in 1854, and the last edition in 1883. This book has about twenty-five pages devoted to rules for curves, nine pages to trigonometry and surveying, twenty-nine pages to leveling, and thirteen pages to mensuration of surfaces and solids and miscellanies. The tables in this volume consist of natural sines and tangents, ordinates, deflection distances, tangential distances, long chords, and board measure. The total number of pages is one hundred and thirty-four. The point that is now generally known as the point of intersection is termed by Mr. Griswold "the virtex." His definition of deflection angle corresponds with Mifflin's definition of the same. Forty-two pages of the book devoted to the art of leveling, mensuration and miscellanies will be found of little service in the field.

The first edition of the "Engineer's Field-Book," by C. S. Cross, was published in 1855. There are in this book twelve pages devoted to curve rules, fourteen pages to curve tables, and twelve pages to the prismodial formula, with table. The total number of pages is forty-three. In this work the principal table consists of tangents for a one degree curve calculated for every minute from naught to ninety degrees. Most of the curve problems in this volume are solved by means of calculations for a one degree curve. There are about ten thousand tabulated computations in this little book. The second edition appeared in 1885. In addition to the aforesaid, this edition contains instructions to division and assistant engineers by Mr. Oliver W. Barnes. Also an article on Engineering Field Work by Mr. Chas. A. Smith, making an addition of about twenty pages. These last two articles, also the article on the application of the prismoidal formula, could be dispensed with in the field.

In 1855 Mr. Charles Haslett wrote a work entitled "The Engineer's Field-Book." The following is taken from the preface: "In presenting this work to the public the author claims for it the adaptation of a new principle in trigonometrical analysis of the formulæ generally used in field calculations. Experience has shown that versed sines and external secants as frequently enter into calculations on curves as sines and tangents, and by their use as illustrated in the examples given in this work. It is believed that many of the rules in general use are much simplified, and many calculations concerning curves and running lines made less intricate, and results obtained with more accuracy and far less trouble than by any methods laid down in works of this kind." This book contains one hundred and forty-one pages made up of thirty-two pages relative to curves, which treats of circular curves, compound curves and reverse curves. The remainder of the book contains tables of radii and their logarithms, natural and logarithmic versed sines and external secants, natural sines and tangents, table for curving railroad iron, &c. Very little of the information given in this volume can be classed as superfluous matter for a field-book, as it deals very directly with the field wants of the civil engineer. This book is now issued bound together with the same author's work on mechanics, thereby adding three hundred and seventy pages to the volume which do not pertain to field work.

The "Pocket-Book for Railroad Engineers," by O. Byrne, was written in 1855 also. It contains about one hundred and sixty pages, of which about eighty-five give rules for a great variety of curve problems. The remainder of the book treats of curve rulers, earthwork, cross sections, leveling, a table of ordinates and a table for earthwork. The following is an extract from the preface:

"All writers on this subject and compilers of pocket books for railroad practice, without exception, fill their works with tables too contracted for use, formulæ and rules too complex for practical men, or empiricisms that give results not sufficiently exact for practical purposes. It is well known that the simplest calculations cannot be made on the ground with any chance of accuracy, without retiring to a tent or house. The most the engineer can do is to store his field-book with topographical or instrumental notes, or with simple angular and linear measurements. Hence all helps to perform extensive calculations on the ground are useless." The method for laying out many of the example curves given in this volume is by means of offsets and chords. The most of them are solved by very elaborate algebraic demonstrations, some of which cover a whole page. This explains, perhaps, why Mr. Byrne preferred to use his field-book in the office.

The first edition of "The Field Engineer. Prepared with Special Reference to the Wants of the Young Engineer," by W. F. Shunk, appeared in 1879. Its contents is as follows: Explanation of the table of logarithms, occupying eight pages; plane trigonometry, ten pages; vertical curves, four pages; rules for curves and turnouts, seventy-eight pages; duties of field men, five pages explanation of the curve protractor, six pages; triangulating obstructions, four pages; together with the following tables: turnouts, radii and their logarithms; square and cube roots; loga-

rithms of numbers, sines and tangents; natural sines and tangents; chords, versed sines, external secants and tangents for a one degree curve, calculated for each alternate minute from naught to ninety degrees, various grades for a mile, &c., closing the work with six pages of advertisements, making a total number of pages three hundred and thirty-six. In article eighteen, Mr. Shunk speaks of the distance between the point of intersection and the point of curve as the "tangent or apex distance;" from this Mr. Trautwine has adopted the term of apex distance in the latest editions of his field-book. In all other cases Mr. Shunk uses the word tangent for what is now generally known as the tangent.

The tangential angle in this book is defined as by Mifflin and the deflection angle as by Trautwine. "The author's principal aim in preparing this volume has been, as its title indicates, to serve that large class of young engineers who, like himself, have not had the advantages of a technical education."

In 1880 the first edition of the "Field Engineering, Designed for Class-Room, Field and Office," by W. H. Searles, was published. This book contains five hundred and seventeen pages devoted to the following : Reconnaissance, seven pages ; preliminary survey, sixteen pages ; theory of maximum economy of grades on curves, sixteen pages ; location, three pages ; simple curves, sixty pages ; compound curves, forty-six pages ; turnouts, thirty-four pages ; leveling, sixteen pages ; construction, thirty pages ; calculation of earthwork, twenty-three pages ; topographical sketching, three pages ; adjustment of instruments, three pages : explanation of tables, fourteen pages. Also the following tables: Geometrical propositions, trignometrical formulæ, radii, logarithms, offsets, etc., tangents and externals to a one degree curve, calculated from naught to one hundred and twenty degrees, long chords, middle ordinates, linear deflections, valvoid arcs. turnouts, middle ordinates for curving rail, elevation of outer rail on curves, various grades for a mile, table for obtaining barometric heights, correction for earth's curvature, and relative co-efficient for reducing inclined stadia, lengths of circular arcs, minutes in decimals of a degree, inches in decimals of a foot, square and cube roots; logarithms of numbers, sines, tangents, versed sines, and external secants ; natural sines, tangents, versed sines, and external secants excavation table, useful formulæ, closing with an appendix of two pages. The terms used in this volume are the same as used by Mifflin and Henck, except the point of intersection, according to Henck, is here known as the virtex, and the introduction of the term of external distance, which Henck in 1882 calls the shortest distance, both meaning the actual external secant.

This book is the most extensive and complete publication on field-work in the English language, and is, therefore, the best for the student. For field use about one hundred and sixty pages could be dispensed with without reducing its merit as a field-book.

The first edition of the "Pocket-Book of Tables and Formulæ for Railroad Engineers," by B. H. Hardaway, appeared in 1886. The following is the contents, printed on about fifty pages : Tables of trigonometrical formulæ ; leveling by barometer, with table ; calculation on earthwork, grades and grade angles, with table ; coefficient for reducing


PRATTVILLE SEWERS
CHELSEA MASS.
SHOWING POSITION OF
FLUSH TANKS
AND
HOUSES
ENTERING SEWERS
NOV. 1886
W. E. McCLINTOCK,
CITY ENG'R
CIRCLES ARE MANHOLES
SQUARES " FLUSHTANKS
HOUSE DRAINS ENTERED
" ROOFS "
GARLAND ST.
FREMONT AVE.
HARVARD ST.
FRANKLIN
WARREN ST.
HANCOCK ST.
CASH ST.
WASHINGTON
AVENUE
LAUREL ST.
WEBSTER AVE.
MURRAY
STREET
JEFFERSON AVE.
WOODLAWN AVE.
LOCKE ST.
FLUSH TANK NO. 1
FLUSH TANK NO. 2
FLUSH TANK NO. 3
FLUSH TANK NO. 4
FLUSH TANK NO. 5
FLUSH TANK NO. 6
FLUSH TANK NO. 7
MANHOLE A
MANHOLE-B
MANHOLE-D
MANHOLE-E
MANHOLE-F
MANHOLE-G
MANHOLE-H
DRAIN FOR HORSE CAR STABLE 200 HORSES
SETTLING TANK
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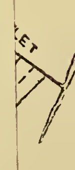

inclined stadia readings to horizontal ones, with table ; radii, ordinates, offsets, and ordinates for curving rails, calculated for each thirty minutes of curvature from naught to twenty degrees ; elevation of outer rail, with table ; turnouts, with table ; table of curve formulæ ; article on transition curves, ending with tables of natural sines and tangents. This little book is intended to be used separately or together with a transit book manufactured especially for that purpose, the cover of the transit book having a pocket into which one of the covers of the field-book is inserted and thereby held inside the transit book.

Summarily, in regard to the terms which are considerably at variance in this branch of civil engineering, the same may be said to some extent to apply to the whole profession. The only way, perhaps, to remedy this evil is by a convention of civil engineers, to arrange a vocabulary of tecunical terms which should be adopted.

The most popular field-books that are now in use are largely made up of information that must necessarily be learned before taking charge of field work, or that apply to field notes after the field work is done. Nearly all of these books are intended for young men who have yet to learn the use of the level. The young man who has not advanced beyond this point in his profession has no use for a field-book. Therefore it is believed that the articles on leveling, cross sectioning, earthwork, reconnoissance, etc., occupy space which could be put to better use.

Many of the authors of field-books write with a view to supply both the young and the old engineers, and many wish to supply both the field and the college. These combinations always tend to lessen the standard of the work. The one must suffer from want of detail or the other must necessarily be overburdened with detail and matter foreign to field work.

The principal cause of the attempt to make so broad a scope with the field-book is the lack of a good text book, which, at the present writing, the profession is without.

CONSTRUCTION AND VENTILATION OF SMALL PIPE-SEWERS.

By William E. McClintock, Member of the Boston Society of Civil Engineers.

[Read May 16, 1888.]

My paper to-night will more especially treat of a small system of pipe sewers that I constructed for the City of Chelsea, in 1883, the way they have worked, with some experiments on ventilation of small pipe-sewers made on this system in 1886.

The system, as constructed, consists of a wood box 186 feet long, across soft marsh bottom, 1,135.3 feet of 15-inch pipe, 1,635.6 feet of 12-inch pipe, 439.5 feet of 10-inch pipe, 1,776.8 feet of 8-inch pipe, 5,933.2 of 6-inch pipe. A total of 11,106 feet.

Manholes are built at each change in the line or grade and at intervening points for the purpose of ventilation and to give easy access to all parts of the sewers for inspection. There are 48 manholes in all, each having a cover with 37 one-inch holes through it for ventilation of the

sewers. The sewer passes through the bottom of the manholes in a half section of the same size as the sewer at its inlet and outlet. All changes in direction or grade are made in the manhole by a short curve, leaving a clear view from manhole to manhole. "Y" branches are placed on each side of the pipes at intervals of 25 feet, with the ends stoppered. Where the depth exceeds 15 feet, 6-inch chimneys are carried up to within about 9 or 10 feet of the surface, with a "Y" branch at the top, so that each side may enter, one at the top and one at the "Y."

The minimum grade is 0.25 foot to the 100 feet; the maximum grade is 15.80 feet to the 100 feet; the average grade is 3.94 feet to the 100 feet.

Seven Field's flush tanks were placed at the dead ends, having a capacity of 150 gallons each. The flush tanks are placed in the sidewalk and are connected into a Y branch about 10 feet from the extreme end, as in all cases the sewer ends in a manhole. All house connections are 4 inch, with traps outside the house.

At the outlet a brick tank is placed, 15 feet long, 6 feet wide and 7 feet deep below the inlet pipe, having an opening 6 feet square at the top, for cleaning out, with a brick arch over the rest of the top. Across the middle of this tank is a stop plank made of 4-inch matched spruce plank, with the bottom 18 inches below the invert of the inlet pipe and the top about the same distance above the top of the pipe. The space between the stop plank and the outlet pipe (6 feet square) is covered by a wire screen of half-inch mesh placed 3 inches below the invert of the outlet pipe and in a horizontal position. On this screen is placed a layer of coarse rye straw 3 inches in thickness, with a coarse wire screen on top to keep the straw in position.

By this arrangement all the lighter matters like paper, bits of wood or cloth and grease are held on the surface of the water above the stop plank, while the heavier substances settle to the bottom and the water that passes off is fairly free from any substance that is repulsive to the eye. In practice the effluent water is but slightly turbid and has but very little odor. The outlet is in a salt creek where the tide covers the marsh grass from two to four times each month, so that any finely divided matter that may be in suspension in the water is filtered out by the grass, and 200 feet from the outlet of the sewer there is no visible sign of sewage matter.

The tank is cleaned out once each month by the man owning the adjoining land, who composts the sewage matter for his farm. No perceptible odor comes from the tank even while it is being cleaned out; ordinarily, when the cover is removed, the smell is barely appreciable when standing directly over the tank. What becomes of the gases I cannot say unless they are held under the thick coating of matter that almost always rests on the surface of the water in the tank.

The building of the sewers was by contract, the city furnishing the pipe. Grades were given every 25 feet by driving spikes in the street on a 3-foot offset from the centre line and leveling on these and working out the cut in each case. Planks were then placed across the trench and uprights of 3 × 1 inch stuff nailed to the planks, and the cut in even feet marked on these. A line was then stretched from stake to stake on a parallel grade with the sewer and at the most convenient distance above

it. A grade pole, marked off into feet, having a strong iron shoe on it, with a piece extending out sufficiently far to lay into the end of the pipe, and stiff enough to lift the pipe at one end, while laying, if necessary, was used, and the grade of each length of pipe was given. The alignment of the pipe was kept good by plumbing down from the line. The pipes were laid as closely to an absolutely straight line as was possible. As a proof of what success we had in this direction, a stretch of 6 inch pipe, 900 feet long, could be looked through by using mirrors, the pipe being laid for that distance on an uniform line and grade. After the work was completed the sewer between each manhole was carefully examined and all foreign matter removed. Several brickbats and two half-round cleaning-pieces, fastened to a 3-foot stick, were among the things removed.

The cost of the work was as follows:

Tank	$327.00	Inspection	$756.75
48 manholes	2,506.63	Printing	49.10
Pipe	3,449.77	Sundries	329.74
Trenching	7,461.04	Flushing	750.72
Cleaning up	693.25		
"Ys"	355.75	Total	$16,679.43

I do not know as it would have any particular bearing on any other work to go into more particulars as to the cost. In order to get an outlet we had to excavate to a depth of about 23 feet for some distance on one line. Along this section the 6-inch chimneys were placed.

It would not be fair from the figures given, to say that $8,000 per mile is the cost of a small pipe system, as the outlet and tank, and in fact the most expensive part of the whole district, is completed, while there yet remains 14,800 feet of small pipes, with no specials, to lay in order to complete the district, at an estimated cost of $18,968. If we add this to the actual amount expended to date, it would give us $35,647.75 as the cost of 26,800 feet, or 5.075 miles, or about $7,000 per mile.

According to an estimate made by myself at the time the subject was before me, the same section would cost for combined sewers the sum of $109,000. I will explain that part of this increased cost rises from the fact that if the street water was introduced the outlet would have to be carried 4.000 feet farther out, or to a point below a tidal dam, as the introduction of storm water, in connection with house refuse, into a water power privilege, would doubtless give rise to litigation, whereas, by keeping out the sand and gravel that comes with surface waters and by screening out the solid matter from the sewage, no obstruction is carried into the pond. As an offset in the other direction, there will have to be constructed at some time in the future a few storm-water sewers at an estimated total cost of $4,000, which, added to the above estimated cost of the pipes, gives us a total cost for the separate system after both lines are completed, $39,647, or an average of $7,812 per mile. Taking the combined system as per estimate, the average cost per mile is $21,477, or about three times the cost of the separate system.

To compare the above estimate with what it has cost in the rest of the city to build the combined sewers already in, we find that there have been constructed 26.69 miles of sewers of all sizes, from 12-inch pipe to 6-foot brick, at a total cost of $400,000, or an average of $15,000 per mile.

This will give a fair average of the completed combined system in Chelsea, as by far the greater part of the city is sewered.

From the above figures it will be seen that the combined system, as actually constructed, will cost from two to three times the separate.

I have no figures to show the cost of repairs of the combined sewers except for a few years back, as no detailed account was kept previous to 1880. Since 1880 there has been expended for repairs and cleaning the sum of $2,500 on all the sewers exclusive of the section under consideration. On this section there have been expended $500; $400 of this amount have been used for cleaning out the settling tank, leaving $100 for the regular repairs and cleaning.

I place no particular value on these figures, as with the small pipes we keep the outlet clean, while in the combined sewers we allow the whole matter to flow where it will. In the one matter of cleaning there is no doubt in my mind that the small pipes can be kept clean by flushing at intervals that must be determined by the particular conditions presented. We have had but two stoppages in four and a half years. These were removed at an expense of about $5. One of the stoppages was caused by three bricks falling into a manhole and stopping in the outlet of a 6-inch pipe. The obstruction was easily located from one manhole and removed by the rods and hoe. The other was caused by an accumulation of grease in a dead end that was removed by the rods and hoe.

The only other cleaning required was the removal of sand from the manholes, as no catch pans have as yet been put in. The sewers are to-day almost as clean as when put in nearly five years ago. From experiments made by myself in 1886, it takes the water from a discharge of flush tank No. 1, located at the extreme end of Washington avenue, 40 minutes to reach the outlet, a distance of 4,900 feet. It is safe to say that everything passes out of every part of the whole system inside of an hour from the time it is placed there, leaving no chance for the generation of gases inside the sewer. There are no appreciable odors even standing over the manholes. In the course of some experiments on the ventilation I have spent hours in the manholes with no ill effect and hardly any discomfort as far as odor was concerned.

From the experiments on ventilation I will now attempt to give a few notes: The experiments were made to show the direction and force of any air current through the sewers, and the effect of discharging a large body of water quickly into a small pipe. Also to show the action of an air pressure caused by the air passing into a sewer at a certain velocity, and whether said current would be able to break the seal of any trap on a branch sewer.

The small map shows the system of sewers as built, and reference to it will show the location of the different manholes and flush tanks which are referred to in the following ventilation experiments.

The velocity of the air was measured by a meter capable of indicating one foot per second. The meter was held in the end of the sewer in such a way as not to decrease the section of the pipe, and yet so as to get the full influence of any movement of air that was passing through the pipe. The trials were made with the manhole cover off and then with it put on. The temperature of the air and sewer was taken, with the direction

and force of the wind. The depth of the manhole where the trial was carried on is given, with the gradient to the next higher manhole.

First Trial.—Manhole A at Eustis street 6-inch inlet, with flush tank No. 1 at the end of 8-inch connection running continuously and discharging as often as full.

Wind westerly, 3,692 feet per second; temperature of air, 48½; temperature of sewer, 53½; manhole 10 feet deep; 8-inch pipe coming in from Washington avenue; 6-inch pipe from Eustis street.

The trial began at 11:08:18 A. M. and continued till 11:51 A. M., a period of 42 minutes and 42 seconds. During this time the air traveled a total distance of about 1,500 feet. The velocity was fairly regular and the direction against the flow of water. The air was flowing at the time the trial was stopped. There were four periods of rest of the air: 1st, 45 sec.; 2d, 9 min.; 3d, 45 sec.; 4th, 1½ min.

Before beginning the above trials the air in the 8-inch inlet of same manhole was tried but its velocity was not sufficient to move the meter. From time to time during the trials a lighted match was held in the 6-inch pipe at different points but at no time did it show the least regular movement in either direction. Particular care was taken to see if the extra flow of water at the time of a flush had any influence on the flow of air, but none was noticeable.

Second Trial.—November 16, 1886. Manhole A, at 8-inch inlet, cover of manhole off; temperature of air 42; temperature of sewer 52.

The trial lasted from 4:36 P. M. to 4:41 P. M., a period of 5 minutes.

The total distance passed over in five minutes was 250 feet; the rate of flow was very regular and against the flow of water.

Third Trial.—Same date and immediately following trial No. 2.

The meter was held for four minutes in the 8-inch outlet of manhole A, and failed to show any movement of air.

The result of the above trials was to show that the air flowed in the opposite direction from the water in the sewer; that the flow might be even and continuous for a long period of time up through the inlet of a manhole with no flow into the manhole from the outlet, showing that the air flowing up the sewer must be supplied through the manhole cover; that at different times the air will flow or will not flow through different inlets or outlets in the same manhole.

Fourth Trial.—November 10, at manhole D outlet. Wind southwest, light. Raining quite hard. Flush tank not running. For a few seconds there was a slight flow of air down the sewer from the manhole. For most of the time there was no perceptible movement of air. A lighted match held in the mouth of the sewer showed an occasional slight disturbance of the air. A lighted match held so as to just clear the water showed a slight movement of air with the water, but this did not extend a quarter inch above the surface of the water. The observations lasted 10 minutes, during which time the air in the manhole was very good, there being no perceptible smell.

Fifth Trial.—November 10, at Manhole D inlet, with the same conditions as in No. 4. A slight current of air was observed up the sewer from the manhole, lasting a few seconds. A lighted match held in the mouth of the sewer showed a slight movement of air back and forth, but not

enough to measure. A lighted match held very close to the water showed the same results as in the last trial. The sewage flowing through was about ¾ of an inch deep. The trial lasted about 10 minutes.

Sixth Trial.—Same day and same conditions as in the fourth trial. Manhole D outlet; flush tank running.

There was one trial at the outlet and three at the inlet of this manhole made for the purpose of determining the effect of a flush on the air at a point 300 feet away, with a grade between the two points of .53 foot per 100 feet.

The first trial, at the outlet, showed no air moving before the trial began or after it closed. The air began to move in the direction of the water 35 seconds before the head of the flush water appeared at the manhole, and continued to flow for 5 seconds after. The total distance traveled by the air was 32 feet.

The second trial, at inlet, shows the air moving 1 minute 25 seconds ahead of the water and 25 seconds, after traveling 86 feet.

The third trial, at inlet, shows the air moving 1 minute 45 seconds ahead of the water and lasting 15 seconds after, traveling 63 feet.

The fourth trial shows the air moving 1 minute 32 seconds ahead of the water and lasting 5 seconds after.

The flow of air in the sewer when the flush tank was not running was hardly perceptible. At a point very close to the water there was a slight movement, but so slight as to be unmeasurable.

Seventh Trial.—At manhole E outlet, November 10, A. M.

Flush tank not running.

a, with manhole cover off, showed a steady flow for 6 minutes 10 seconds, equal to 800 feet, the air flowing against the water.

b, with the manhole cover on, showed a steady flow in the same direction for the same time, equal to 720 feet. The rate of flow after the first minute did not seem to be affected by the cover being on or off.

Eighth Trial.—Same conditions as in last. At inlet of manhole E. November 10, A. M.—This trial lasted 7 minutes, and indicated no flow for the first 2 minutes 20 seconds; flow up of 97 feet in the next 3 minutes 40 seconds; flow down of 30 feet in the next 20 seconds; flow up of 14 feet in the next 40 seconds. The total flow up was 84 feet against the water, in the 7 minutes,

Eighth Trial.—Manhole E outlet, November 16, 300 feet from flush tank No. 1: Wind northeast, 3.98 feet per second; temperature in air, 42; in sewer, 52. Manhole cover off, to show the action of a flush.

The trial shows that the flush seems to exert no influence on the flow of air either at the inlet or outlet. The flow of air at two trials, one with the flush working, the other with it not running, was variable in quantity but at all times against the water.

Ninth Trial.—At manhole F, November 10, 1886, inlet = 150 feet from tank No. 1.

Flush tank working.

No movement of air was felt 20 seconds after the tank started to flow, and stopped when the water had about half passed the point of observation. The air flowed with the water for 60 seconds, and traveled 93 feet in that time.

A second trial at the same point showed the tank as starting at 0; air started in 20 seconds; water at point of observation in 53 seconds; maximum flow of water (by estimate) at 1 minute 15 seconds; air stopped 1 minute 25 seconds: air traveled 92 feet.

A third trial at the same point showed the tank as starting at 0; air started at 10 seconds; water at point of observation at 49 seconds; air stopped at 75 seconds. The air flowed with the water 98 feet.

Tenth Trial.—Manhole F, inlet, wind northwest 3.98 feet per second; temperature air, 44; temperature of sewer, 52; tank not running; cover of manhole off.

The air flows in and out, but mostly out, against the water. In the first 11 minutes 20 seconds, the air traveled 384 feet. At this time the cover was taken off, when the velocity slackened up for 2 minutes, when it again moved as at first, passing over 472 feet in 14 minutes 40 seconds.

At the inlet we found that with the cover off there was a generally upward flow, when the air stopped moving, and at the end of 1½ minutes started to flow down and continued to so flow during the rest of the trial, which lasted 9 minutes. The total flow up was 348 feet. The total flow down was 285 feet. The cover was put on the manhole 40 seconds before the upward flow stopped.

This manhole is 10 feet deep and on a grade of .5 per 100 feet, and is 150 from the extreme end of the line on this section.

The experiments seem to show that there is a flow one way or the other most of the time. That from the outlet it passes through the manhole and up the next section part of the time. That part of the time the air passes directly out of the manhole, and with the cover on draws from the next section, causing the air to flow down.

There is nothing to show that the air passed down from manhole E, with the water, except when driven for a few seconds before the flush water.

Eleventh Trial.—At manhole G, November 9.

There seemed to be a current of air either in or out of this manhole all the time except when the flush tank started up, when there was generally a short rest.

Twelfth Trial.—At manhole foot of Fremont Avenue, November 16, 1886, wind northwest, 3.83 feet per second; temperature air, 42 Fah.; temperature sewer, 52 Fah. No flush running. Cover of manhole on.

Trials were made at both outlet and inlet, and both showed a steady upward flow of air. The outlet trials lasted 7 minutes, and during that time the air flowed 500 feet. At the inlet the trials lasted 13 minutes, and during that time the air flowed 850 feet.

This makes the average rate of flow into the manhole 71 feet per minute, and up the inlet out of the manhole 65 feet per minute.

The grade of the sewer between this and the next manhole higher up the hill is 8.75 feet per 100 feet; the distance 360 feet.

Thirteenth Trial.—At manhole Fremont avenue and Laurel street, November 16, 1886; temperature air, 42 Fah.; temperature of sewer, 52 Fah.; wind northwest, 3.83 feet per second; cover of manhole off.

A trial for 5 minutes at the inlet showed the air to have traveled 440 feet, or at the rate of 88 feet per minute, the flow being very regular.

A trial of 8 minutes at the outlet showed the air to have traveled 386 feet, or at the rate of 46 feet per minute, showing that considerable more air passed up through the sewer from Fremont avenue to Laurel street than came into the manhole from the lower section sewer, the excess passing in at the manhole cover.

Fourteenth Trial.—At the manhole Laurel street and Garland street. Same day and same conditions.

A trial of 6 minutes showed the air to have traveled 450 feet, or at the rate of 75 feet per minute. This is the highest manhole in the section, in fact, the highest in the system.

Other experiments were made at different points but were not carried far enough to draw any conclusions from and are therefore omitted from this paper.

As a result of all my experiments I find that with a good grade there is always sufficient movement of the air to thoroughly ventilate the sewers many times each day. On the lighter lower sections the flow of air seems to be less active or constant, and as yet I am unable to state whether there is sufficient movement to ventilate to any extent. I find that the air passes in at some manholes and out at the next higher ones, ventilating the short section between the two.

The question that is now raised in my mind is whether by a careful study and actual trials the partial vacuum created in a sewer on a high level with a good grade can be made to extend its influence through the sewers to the lower levels where the normal action is very slight. If this is done, it may be done by placing close covers on certain manholes along the sewers to cause the air to be taken at a point nearer the outlet, while by intermediate close covers the outlet for the foul air will be placed at a higher level or even at the summit.

If this system can be made to work, the sewers will be thoroughly ventilated their entire length.

The possible objection to such a scheme might be that the foul air being concentrated at one point on the summit would tend to cause a nuisance at that point. At the same time if the ventilation could be effected, it might be an easy matter to take care of that part of the question. I think it a matter well worth the time and trouble to investigate more carefully and for a longer time.

Of course it follows as a matter of fact, that the oftener the air is changed the less foul it becomes, and the easier to handle, and if by a proper application of close and open covers, a current could be induced to flow nearly continuously through the sewers. I imagine we should hear but little complaint of the excess of foul air at any one point. As a matter of fact, I have been surprised at the remarkable freedom from foul odors in these small pipes, and at the clean condition after nearly five years use.

The experiments made on the air of these sewers are only a beginning of what should be carried out to give an intelligent idea of the flow of air through them. I for one have placed ventilated covers on my manholes because other engineers have said they ought to be there. At the present time I am far from satisfied that they should be placed at random along a line of sewers without knowing the effect they will have in the end.

DISCUSSION.

Mr. F. P. Stearns : I take it for granted that the time has passed for engineers to discuss whether the "separate" or the "combined" system of sewerage should be used exclusively ; and that we have reached the point when both systems are considered with reference to their applicability to the city or town to be sewered.

The separate system of sewerage was first applied in this country on a large scale but eight years ago in Memphis. Since the introduction of the system there, the number of systems built per year has increased until there are now in the United States a total of as many as 36, and they are being built more rapidly than ever.

Most of the features of a system of small sewers are simple enough to any engineer experienced in the construction of larger ones ; yet there are many details which must be based largely upon experience with the same kind of sewer to obtain the best results.

With a view of obtaining the latest information upon certain points from those having practical experience in the construction and operation of these systems, I caused a circular to be sent to those in charge at various places and have received many replies. It is my chief purpose, in taking part in this discussion, to present the substance of these replies, and of some others relating to the maximum rate of consumption of water during the extremely cold weather of last January.

The volume to be provided for in a small pipe system consists of domestic and other wastes, which may be called the sewage proper, and of ground water, with or without the addition of roof and flushing water. Where there are no overflows it is necessary to provide for the maximum combined flow from these different sources.

The sewage proper is in most cases about equal in volume to the water supply, and this reaches its maximum rate in this climate in severe cold weather.

The week ending the 28th of last January was extremely cold, and the consumption of water in several instances was reported to be higher than ever before known.

In answer to inquiries made at that time returns were received from which the following table has been deduced :

City or town.	Average daily consumption per inhabitant.	Maximum daily consumption per inhabitant in Jan., 1888.
Boston, Mass. (Cochituate and Mystic works)	79	151
New Bedford, Mass	85	150
Brookline, Mass	71	100
Providence, R. I	39.5	54
Waltham, Mass	39	50
Newton, Mass	31.3	50
Taunton, Mass	31	43

These figures, giving the maximum daily consumption of water, show a very great diversity under what may be called somewhat similar conditions, and they show forcibly that a large allowance must be made in the capacity of the sewers to provide for the increased rate at which water is used on exceptional occasions.

The figures here given do not really give the greatest rate of water supply that has to be provided for, as the maximum rate of flow during

certain parts of the day is in excess of the average for the whole day, even during cold weather when so much is wasted at night.

In Boston, records are kept several times a day of pressures in the main at different points, from which it is easy to determine the losses of head between the distributing reservoirs and these points. From these data it was estimated that the consumption during several hours of the very cold weather, already mentioned, was at as high a rate as 170 gallons per inhabitant, or 2.1 times the average rate of consumption during the year.

Infiltration of ground water appears to take place when sewers are built through wet ground, even when great care is taken to prevent it. It is obvious that to exclude it wholly, not only the sewers and house connections must be tight, but no drainage of wet cellars can be permitted.

The replies received in answer to the question in the circular with reference to the infiltration of ground water are as follows:

Cedar Rapids, Ia.—" There is considerable ground water which has not been measured."

Chelsea, Mass.—" Ground water about one inch deep in 15-inch outlet."

Kalamazoo, Mich.—" Some ground water finds its way into the system, estimated from data taken before the sewers were open for public use to be 20 per cent. of the capacity of the mains."

Norfolk, Va.—" No accurate estimate made, but ground water forms at least 60 per cent. of pumping." From information given elsewhere in the returns the maximum flow is found to be about 167 gallons daily per inhabitant connected with the sewers. Of this the ground water, estimated at 60 per cent, equals 100 gallons.

Schenectady, N. Y.—" The sewers are laid through wet ground and quicksand in some instances. The Erie Canal seepage also affects them in a small degree. Measurements made at about the time the system was completed indicate that the infiltration of ground water amounts to about 5 per cent. of the capacity of the mains."

This completes the information on this subject furnished by the replies. They indicate that where sewers are built through wet places the ground water is an important element.

Additional information on this point is furnished by the experience on the main drainage works of Boston. In February, 1887, at a time when no surface or storm water entered the sewers the daily flow by measurement in the reservoir was as high as 147 gallons per day for each of the 273,000 inhabitants then connected with this system of sewers. The average daily consumption of water in Boston per inhabitant during that month was 84 gallons; in the district connected with the sewers say 90 gallons, leaving 57 gallons to be accounted for by the infiltration of groundwater.

A portion of this, perhaps 12 gallons, is sea water, leaving 45 gallons, more or less, of fresh water.

To the question, " Do you exclude roof water?" seven answer " Yes," five answer " No " while seven answer that roof water is mostly, but not wholly excluded from the sewers. Some of these admit it from public

buildings, others from private buildings at dead ends by special permit and it is also mentioned that, though theoretically excluded, some of it does find its way into the sewers.

The answers to the question, "Do you use 6-inch pipes for laterals and if so, do they operate successfully?" furnish the following information:

Nine use 6-inch pipes.

Two use 7-inch pipes.

Seven use 8-inch pipes.

One uses 10-inch pipes.

One uses 6 or 8-inch pipe, the choice depending upon the grade.

With regard to the operation of the 6-inch sewers, seven answers were received, in two of which it was stated without qualification that these sewers operated successfully, while the other answers qualified this statement. The opinions on this point can be better understood by quoting from the answers.

Cedar Rapids, Ia.—"We use 6-inch laterals on runs not exceeding 800 feet and grade of not less than 2 per cent."

Chelsea, Mass.—"Six-inch laterals operate successfully. We have as yet had no trouble of any kind. Minimum grade, 0.25 per cent."

Kalamazoo, Mich.—"They operate satisfactorily for residential portions under favorable conditions. Minimum grade, 0.48 per cent."

Keene, N. H.—"We have had no obstructions on our high grades except from roots, * * * but on our low grades we have an occasional stoppage, which can usually be removed by a stream from our hydrants."

Nahant, Mass.—"Six-inch laterals work well on grades varying from 0.5 to 2.0 per cent." Each house is provided with a large grease-trap, through which the waste from the kitchen sink passes on its way to the sewer.

Norfolk, Va.—All laterals begin with 6-inch pipe. On anything under 0.75 per cent. grade a flush tank is used at end of lateral. The general statement was made on the return that these sewers operated in a satisfactory manner, but that it is not entirely satisfactory may be judged by the following quotation from a letter received from Mr. W. T. Brooke, City Engineer, who suggests "that nothing less than an 8-inch pipe be used on laterals, for although theoretically the 6-inch may be all sufficient, yet from experience with the difficulties attending the misuse of house connections with the sewers, I am forced to regard 8-inch pipes as practically the best."

Wilkes-Barre, Pa.—"Grade 0.5 per cent. operating successfully; distance from flush tank to main sewer 500 feet. Would not advise the use of 6-inch laterals for greater distances or less grade than the above." * * "I have discontinued the use of 6-inch laterals and use 8-inch instead."

Mr. Chas. N. Wood, City Engineer of Norwalk, Conn., writes that the sewers of this place are of the combined system, but that he has had some experience with 6-inch pipes, in separate systems of sewers, and believes that when the grades are 6 inches or more per 100 feet, and adequate flushing appurtenances are attached, they will work well as laterals. In another part of his letter he states: "I believe the separate

system to be *the* system, on account of cost, sanitary benefits, etc. Yet I think the tendency is to use too small pipes on light grades."

As the question asked did not refer to the operation of sewers larger than 6 inches in diameter, few answers were received concerning them, but all statements that were made were to the effect that they operated successfully.

I will quote two of the replies to the question: "Is there any special feature you would remedy in new work?"

Keene, N. H.—"On streets that have elm trees near the sewer would recommend that especial care be taken to make tight joints, so that roots cannot find their way into the pipe. We have been troubled very much on sandy soil with the pipe becoming filled with roots. The bottom of our pipe was not properly cemented, which allows the water in the pipe to leak into the ditch, thus attracting the roots, and several of our 6-inch lines have been badly obstructed."

Pawtucket, R. I.—"In the original design the water was carried upon the surface of the street too long. In constructing sewers for the last two years I have extended the sewers taking street water to greater lengths than shown on the original design."

In summing up the information received as to the different features of these systems it must be admitted that the weight of the evidence is rather in favor of the use of a sewer larger than 6 inches in diameter for the smallest size, particularly on light grades.

The lightest grade much used for laterals is about 0.5 per cent.

The maximum flow in sewers from which roof water is excluded will occur when the total volume due to domestic and other wastes, and to the infiltration of ground water is greatest. The wastes are greatest in this climate in extremely cold weather. The infiltration is probably greatest about the time the frost comes out of the ground. The consumption of water in the severe cold weather varies very much in different places with the habits of the people and the measures taken to restrict waste, consequently no definite amount can be stated which will apply to all places. In Boston it is at the rate of about 170 gallons per inhabitant per day.

The amount of infiltration of ground water is also a variable quantity, depending chiefly upon the length of sewer and house connections in wet ground, and upon the care taken to make them water-tight. The answers received indicate that the volume may be very large in some cases, and that no ordinary care will prevent a considerable quantity from finding its way into sewers laid in wet ground.

Whether or not roof water should be admitted to the sewers is not settled by the answers received; nor does it appear to me that it could be, as it must be settled by the local conditions and the cost. It is desirable as a sanitary measure to admit the roof water, and its admission will not generally make the cost excessive when the crude sewage is to be discharged into a stream of water not far distant. When, however, a long main sewer is required to carry the sewage to a suitable point of discharge, or when pumping or purification is required, the cost of dealing with the larger volume will frequently make it undesirable to admit it. For an approximate example of the increase of volume to be provided

for when roof water is admitted, assume that six persons live under a roof having an area of 1,000 square feet, that the maximum rate of flow of sewage and ground water equals 200 gallons per day per capita, and that one inch per hour of rainfall can be collected from the roof.

With these assumptions the flow of sewage and ground water would be at the rate of 1,200 gallons per day, and the flow of roof water at the rate of 15,000 gallons per day, a ratio of 1 to 12½.

In addition to names already mentioned, the following persons have furnished the bulk of the information herein quoted, and to them and to the others who so kindly answered my circular of inquiry I here desire to express my obligations :

Mr. Geo. S. Pierson, City Engineer, Kalamazoo, Mich., who also furnished information with reference to Schenectady, N. Y.

Mr. A. R. Sweet, Engineer and Superintendent of Sewers, Pawtucket, R. I.

Mr. W. B. Pierce, Borough Engineer, Stamford, Conn.

Mr. C. F. Ingham, City Engineer, Wilkes-Barre, Pa.

Mr. G. A. Mitchell, City Engineer, Cedar Rapids, Ia.

Mr. D. H. Sawyer. Superintendent of Sewers, Keene, N. H.

I also desire to acknowledge my indebtedness to Mr. Wm. M. Brown, Jr., of this city, who has taken a prominent part in the collection of the information.

Mr. F. Floyd Weld, City Engineer, Waterbury, Conn. (by letter):

Our practice here is to admit roof water, and rather encourage the arrangement of house connections to take it. The roof water is clean and acts as a good flush to the sewers when it rains, and if taken in the sewers does not run over sidewalks to freeze and make dangerous icy places, nor saturate the ground about houses, and run down outside cellar walls to make wet cellars.

In proportioning laterals I use the roof area, and in the case of outside residence streets which are not built up, I use an area which is the same as on some street fully built up, or which in all probability will have no more houses upon it. In the central or business portions the sewers are proportioned for a street closely built up to a depth of 100 feet from the street on each side; and allowance for one inch rainfall per hour is made. I use no laterals smaller than 8 inches diameter, and the house connection hubs or Y branches are all 6 inches diameter. In laying the house connection pipes, either 6-inch or 5-inch pipes are allowed (after the first pipe from the sewer), but nothing smaller than 5-inch can be used until the soil pipe inside the house is reached, where 4-inch is the smallest allowed. Our experience shows that a 5-inch pipe is the best size for the connection from an ordinary house. For large stores, hotels and some other large buildings we use 6-inch connections.

The lightest grade we have on an 8-inch lateral is 0.5 per cent., which is lighter than I would use if it were possible to get more grade.

I find that where an 8-inch lateral has a grade of less than 1.0 per cent. we have to give it special attention in the matter of flushing and cleaning. On the main sewers, which are of brick, we have grades as low as 0.1 per cent.

There are four flush tanks in use on 8-inch laterals. These give a good flush at the upper ends of the sewers, and would be used here in many places were it not for the objections of some of the city fathers to the cost of water to supply them. For flushing I depend principally upon a portable tank, arranged to deliver water from the under side into a tube leading down from the top of the manhole to the sewer pipe at the bottom of the manhole. This tank is an ordinary watering cart, such as is used in cities for sprinkling the streets, and the valve is opened by a lever on top of the cart. The flushing effect of a load of water discharged into the sewer in this way is excellent, far surpassing the flush from any automatic tank, on account of the larger quantity of water and greater head available.

The tube is made of galvanized iron, formed with a bend at bottom to fit into sewer pipe, and with iron braces at top to rest on manhole head. With this portable tank I can flush from one manhole to another and do not have to depend upon the flush from the extreme end only. My manholes are placed about 150 feet apart, the distance varying somewhat with grades and changes of direction.

We have never had a stoppage in a street sewer pipe, and I think the short intervals between manholes has helped to give us this freedom from stoppages by affording plenty of points for inspection and flushing.

We make the joints on pipe sewers with cement mortar only, and have used no special method for making water tight joints, except in the case of a cast-iron pipe sewer laid in the bed of a river, where I used rope yarn dipped in cement paste and calked into the joint.

I have made no comparisons of cost of double and single systems, although I have used both or either one as seemed best in each particular case, others questions than cost usually determining which to use.

Mr. George T. Nelles, City Engineer, Leavenworth, Kan. (by letter):—I am now and always have been an advocate for the admission of roof water. My experience here has been that even with strict regulations to the contrary and close watching, that more or less roof water finds its way into the sewers from cistern overflows, yard slop sinks, and by direct connection with the sewers during storms. This being the case, and in view of the very small additional cost of the pipe necessary to carry the roof water, why is it not better to figure on the roof water from the beginning, and thus avoid future possibilities?

I have found some of our 7-inch sewers absolutely full during heavy storms without being able to locate the source. The continuous flushing during storms is an advantage that should not be underrated. Our city regulations specify 4-inch house connections. This is the source of over 90 per cent. of our trouble with the sewers. With sewers proportioned to carry the roof water a 6-inch house connection could be allowed, and in my opinion would be a great advantage. A 4-inch connection requires much more care on the part of the householder than most of them are willing to give the matter. Probably 95 per cent. of the complaints that come to this office of stoppages are due to this cause. Faulty construction has proved the most fruitful source of trouble here. Some of our early sewers are both out of line and grade. And notwithstanding

regular flushing there is a constant tendency to silt up in the low places. Our more recent sewers have all been built to a light, and none have been accepted unless the light could be plainly seen between all points on the same grade and line. The sewers so constructed have never given any trouble and are to-day perfectly clean and free from deposits. We rarely build laterals on less than a 1 per cent. grade.

Flushing tanks and manholes are essential to the successful operation of small pipe sewers. By the use of flushing shafts or lamp holes a certain percentage of manholes can be avoided on straight lines. But manholes should be placed at each change of grade or line. I have found the lamp holes a valuable help in the location of stoppages and the cleaning of silted sewers.

If called on to design a system of small pipe sewers I would, from my present experience, place the minimum size for laterals at 10 inches, and believe that in this way many of the troubles incident to the use of smaller pipe could be avoided at small additional cost.

Mr. W. B. Pierce, Borough Engineer, Stamford, Conn. (by letter): The separate system of sewers at Stamford is not fully constructed and only a portion is in operation, but a few notes may be interesting. The system was designed by Col. George E. Waring, Jr.

The borough is generally very flat, requiring the use of light grades, the minimum being those given by Baldwin Latham in his "Sanitary Engineering" for a velocity of 2 feet per second when running half full (see American edition, page 11).

The estimated length of each size of pipe in the system is as follows:

	Lineal feet.	Per cent.
6 inch	44,878	63.55
8 inch	11,354	16.08
10 inch	8,137	11.52
12 inch	2,077	2.94
15 inch	3,160	4.47
18 inch	1,015	1.44
	70,621 = 13.375 miles.	100

No roof water is admitted, all flushing being done by the use of Field's flush tanks, of which 72 have been provided, three being of 1,000 gallons and 69 of 150 gallons capacity. There are 31 manholes on the system, those on all pipes of less than 12 inches diameter being merely for access to hand-holes, the sewer pipe being carried through the manhole.

The main feature of the system is the disposal of the sewage, which is delivered by the main sewers into a well on Canal street and is then pumped into deep water in Long Island Sound.

The well is 8 feet in diameter, with 12 inches ring and 20 feet deep, the bottom being about 15 feet below mean high water. While building it, constant pumping of some 1,200 gallons per minute was required. It is plastered with neat Portland cement, and no leaks have been discovered since its completion. Three pumps, with a capacity of 300 gallons each per minute, have been provided—two of the pumps being intended for use in case of accidents or repairs. They are operated by three 4 horse-power "Otto" gas engines, and have been working fairly well.

The pumping main is 12 inches diameter and 7,200 feet in length ; 6,000 ± feet of which is of salt-glazed vitrified pipe, and 1,200 ± feet of cast iron. The main has given fair satisfaction, a few leaks only being noticed, although the head at times has been 20 feet. A stand-pipe is provided at the pump house. Six hundred feet of the iron pipe was laid under water, and here some difficulty was experienced, as the water was too deep to work in without a diver.

The method pursued was as follows: For a long distance the line runs across a mud flat, which is bare at low water. Here the 600 feet of pipe was laid on a small platform about 15 inches wide, to which it was lashed after the caulking was completed. When all was ready, oil barrels were attached to the raft, and at high water the pipe floated. It was then towed to place and moored, and as the tide fell off, the pipe grounded. The barrels were then removed and the operation was complete. The outer end rests on hard sand, which is not protected from washing by the effluent, but although the pumps have been in operation nearly 10 months there has been no perceptible wash.

The operation of laying the iron pipe seems very simple, but it required considerable good management to insure a success. A quiet day, with little or no wind, and even that off shore, was necessary. On the day of the first trial all the conditions were favorable, but with the ebb of the tide came a change of wind, which soon laid the pipe and barrels high and dry on the shore, broadside to.

A large part of the sewers, probably 75 per cent., was laid in very wet ground. The whole Borough, in fact, is underlaid with a water-bearing stratum of gravel, and in many cases continuous pumping was required. Especially was this the case in the district lying near the canal, a large portion of this section being originally salt meadow intersected with numerous small drains which caused much trouble.

On the line through John street, where 1,500 feet of pipe is laid, through this same gravel, 700 gallons per minute were often pumped. This pipe, which is now probably under 8 feet head, was laid with Stanford's Patent Joint and the leakage is trifling.

There is one feature of the work which may account for much of the leakage. With a view of protecting the sewers from possible breaks by plumbers and drain-layers, a 2-feet length of 4-inch pipe was inserted in each of the Y's. In some cases it has been found that the settling of the back filling has started the joints of these 4-inch pipes, causing small leaks. In dry soil this feature is a success, and in a gravity system these extra lengths should always be inserted ; but in wet soil, with a pumping system, it will not be well to use them.

Drain tiles were provided and used in the beginning of the work until it was found they would be approximately as large as the sewers, after which their use was discontinued.

A large portion of the system is now in use. The first house was connected November 23, 1887, and at present there are 70 houses connected, using the following fixtures :

Water closets	117	Slop hoppers	4
Bath tubs	135	Sinks	135
Wash bowls	98		
Wash tubs	58	Total	549
Urinals	2		

The house connections are all 4 inches diameter and through them the sewers are ventilated, no fresh air inlet being permitted on a soil pipe.

In addition to the house sewage system, there has also been constructed a "separate system" for the removal of storm water only. This system is about two miles in length, and ranges from 12 inches to 48 inches diameter. There are 8 manholes and a gravity outlet into the canal.

The cost of the entire system complete will be about $125,000, of which about $15,000 will be for superintendence, legal expense, land damages, etc.

Mr. A. R. Sweet, Superintendent of Sewers, Pawtucket, R. I.: While the admission or exclusion of rain water from roofs may be governed somewhat by soil and climate, I consider that it is advisable to provide sufficient capacity to the sewers for its care. In a town or city subject to the severe winters of our Northern States, the admission of roof water to sewers or special drains is imperative. It would in winter, owing to ice, be dangerous to life and limb to allow water from roofs of buildings to fall upon or run across sidewalks.

The available filtering or absorbing area of the ground in business protions of our towns and cities has been reduced so greatly by streets and buildings that it cannot care for roof water in addition to the water that naturally falls upon it. I do not believe that the admission of rain water to sewers can be entirely prevented. In Memphis, where probably greater efforts than in any other city in the United States have been made to prevent the admission of storm water, I found, upon inquiry, that the flow in the sewers was considerably increased during rain storms.

The maximum allowance of sewage per capita is estimated for Pawtucket at 10 cubic feet in twenty four hours (that being the basis upon which the water-works were constructed) one half to flow off in eight hours.

In determining the size and length of laterals in the suburban part of the city, allowance is made for one inch of rainfall per hour falling upon 5,000 square feet of roof surface per 100 feet length of street or sewer.

The minimum size for lateral sewers in Pawtucket is 8 inches in diameter. I decided to recommend that size after considerable inquiry in other cities using smaller pipes. I found that 93 per cent. of all the stoppages reported in cities using small pipes were in 6-inch pipes, while but 4 per cent. were in 8-inch pipes. The system has been in use four years; we have had but one stoppage of a sewer and that was in a lamphole on an 8-inch pipe sewer, caused by an iron being dropped through a ventilating cover. I recommend for buildings used for residences 4-inch house connections and for business buildings 6-inch connections.

The minimum grade for pipe sewers, 8 to 10 inches in diameter, should be one in 200, and for mains, not less than 18 inches in diameter, one in 250.

I consider the flush tank the life of a small pipe system of sewers, for without it the system will be expensive, troublesome, and unless the greatest diligence is exercised it will surely fail. I had a good oppor-

tunity to test the value of flush tanks. In the year 1884 we had laid about three and one-half miles of small pipe sewers, about two-fifths being 8 inches in diameter. These sewers were in use without flush tanks from April and May, 1884, to June, 1885. In this short space of time (a little more than one year) they had become foul and ill-smelling. There was considerable of a deposit upon the bottom of the sewers, a thick vegetable growth upon the sides, and at manholes the inverts were one-half full of sand; in fact, the sewers were fast filling up. Flush tanks (thirteen in number) were put in operation in June, 1885. They, without any assistance, cleaned the sewers of sand and all deposits and have kept them in good condition.

In the year 1886 it cost the city of Pawtucket more to wash out two sewers without flush tanks (one built in 1876 and one in 1879), the combined length of which was about 2,000 feet, than any two miles of sewers in the city, and it is fair to say that they were clean but a few days at a time ; while if there had been flush tanks they would have been clean all the time.

There are in use in the city of Pawtucket 23 Rogers Field flush tanks as improved in the year 1885 and patented in 1886. The water for these tanks is taken from the city water mains and costs the Sewer Department $10 per year per tank. These tanks operate once in about fourteen hours. They have been in operation some of them nearly three years. We have not found one inoperative, neither has there been one cent laid out on them for repairs.

For ventilation of sewers as well as for inspection, I use manholes and lampholes with perforated covers.

Until such time as our plumbers become experts upon siphonage and ventilation, until cities and towns have complete control of the plumbing of buildings, and none but competent inspectors are employed, it will be more safe to ventilate sewers by openings in the centre of streets than through the soil pipes of buildings, as recommended by certain engineers.

The only city that I know of (Memphis) that built its sewerage system almost without manholes has, since the system was completed, built a number of them for inspection.

The sewerage system of Pawtucket is so designed that by the use of intercepting sewers the sewage is collected and discharged below the lower dam into tidewater, where, except for an hour at high tide and during low water in the Blackstone River, there is a strong outward flow. During storms exceeding one-fourth inch per hour the storm water and sewage is discharged direct through storm overflows into the river.

The sewerage system of Pawtucket, while partaking of many features of the separate system, is not a separate system as commonly known. The laterals are, as far as practicable, designed only for house wastes and roof water, the storm or surface water that falls on the streets being kept upon the surface until the main sewer is reached. Thence it is carried in the same channels as the sewage.

The ground water is collected and carried under the sewers to the storm overflows, or that was the plan. Two of our tile drains are now

stopped, and the water is forced into the sewer through the joints in the invert blocks.

I have found by experience in suburban districts (except in excessive showers, which occur but once or twice a year) that the storm water falling upon two to three thousand feet length of street surface and abutting areas, depending upon the grade of the street, can be allowed to flow in the street gutters without inconvenience to the traveling public or injury to the surfacing material of the street, and what little injury does then occur can be repaired for far less than the interest on the cost of increased dimensions of sewers and appurtenances.

The estimated cost of the sewerage system of Pawtucket complete, including the East District, is about $16,500 per mile. Without the East District, the estimated cost is $13,500 per mile. The cost of all sewers constructed to date, which includes all but about 3,000 feet of the brick sewers in this system, is about $21,000 per mile. One sewer alone in the East District 3,200 feet in length cost $36,000, it being through ledge.

The estimated cost of the sewerage system of the town of Lincoln, designed and partly constructed under my direction, is $17,600 per mile. This system, although less than one-fourth the length, required the use of a greater percentage of brick sewers and large pipes than that of Pawtucket.

Mr. Geo. A. Kimball: In 1886, I designed and partially constructed a small pipe system of sewers for the City of Somerville. The system was designed for a territory of about 40 acres, the outlet being into the combined system, of which about 38 miles had been constructed.

The system was intended to receive roof water and a certain quantity of storm water, a portion of the storm water to be admitted through catch-basins provided with *small outlets*, the streets being graded in such a manner that the *surplus* storm water would continue down the street gutter to a water-course. Connection was also made with two old sewers, designed for sewage and storm water, by means of small pipes connected at the bottom in such a manner that the surplus storm water would continue in the old sewer to its outlet into a water course. The connections with the catch basins and old sewers were so arranged that the sizes were adjustible, allowing the admission of such amount of storm water as should be found best by practice. The largest pipe used was 12 inches and the smallest 8 inches. The minimum grade was 0.25 per cent. for the 12-inch pipe and 2 per cent. or more for the 8-inch.

Manholes were built at all changes in line or grade, and were about 300 feet apart. No flush tanks were constructed. The joints were made with cement mortar. The length of that portion of the system constructed was 4,564.2 feet, and cost $5,723.93. About one-half the work was in deep cutting, the deepest being 20 feet.

The outlet was carried under a railroad and two water courses by a siphon of 8-inch cast-iron pipe 90.1 feet in length. The pipes have been flushed with water from hydrants carried through a fire hose into the manholes, from which the ball or "pill" is forced through all the pipes. Where the deposit is considerable, or consists of sand or other solid matter, the outlet at the manhole is plunged, the manhole and sewer above

is filled with water, and the sudden removal of the plug causes an effectual flush.

In answer to the points suggested in the circular signed by the secretary, I would say as follows :

1. Roof-water should be admitted unless the sewage is to be treated, or the outlet is unusually long.

2. Design for 70 gallons per day per capita, with a liberal allowance for storm or ground water, which will vary greatly in different localities.

3. Eight inch for short laterals and 6-inch for house connections.

4. In regard to grade, get all you can, not less than 1 per cent., but I have been forced to use 0.25 per cent., which requires frequent flushing.

5. Manholes should be built at all changes in grade or line; not, however, to be over 300 feet apart.

After twelve years' experience in charge of the maintenance of the sewers in Somerville, I am convinced that a pipe sewer laid with a 2 per cent. grade will require but little, if any, flushing.

This question presents itself. Cannot flush tanks be dispensed with on steep grades? They are expensive and in many places troublesome. It is possible that the financial return to the inventor is a partial explanation of their free use in some cities.

6. I have always used cement mortar for making joints.

7. Special features of construction should be adopted to suit the conditions. In places where the soil is sandy or the streets are unpaved, the sand will find its way into the sewers, and additional means for flushing should be provided, especially on flat grades. In wet or sandy soils unusual care must be used in making the joints tight.

8. Six thousand dollars per mile is a fair estimate of the cost for a small pipe system, while a combined system may cost twice or three times that amount.

On the general question of sewerage, although much in favor of the small-pipe system, I believe that engineers should use the system which best meets the particular case in hand, whether it is the "small-pipe system," the "combined system," or a part of each.

President FitzGerald: In the February number of the *Annales des Ponts et Chaussées*, 1888, Mr. Durand Claye, a leading French authority, reviews the Shone and Waring systems of drainage. The Shone system is dismissed with very few words, but the Waring system is examined with care and in detail. The article ends with the following *résumé:*

"Finally, we believe the Waring, as well as all other separate systems, is based on a sanitary error in assuming that rain-water, the washings of streets, etc., can be discharged into the nearest water-course without inconvenience. The running of water on the public streets is not permissible, without inundating the lower quarters of a city. The separate systems imply then a double system of sewers. On the contrary there is a necessity for constructing the sewers of a city in such a manner as to unite the dirty water from all sources, even including rain-water; excluding, however, heavy storms."

ASSOCIATION OF ENGINEERING SOCIETIES.

PROCEEDINGS.

CIVIL ENGINEERS' CLUB OF CLEVELAND.

JULY 10, 1888: President Whitelaw in the chair; twenty persons present when the meeting was called to order; the number was afterwards increased to thirty odd.

The minutes of the last meeting were read and approved.

As there was no business before the meeeting, Mr. John Walker read his paper on "Cable Railways," which was discussed.

[*Adjourned.*] JAMES RITCHIE, Secretary.

ENGINEERS' CLUB OF KANSAS CITY.

JULY 28, 1888.—An excursion was taken to Leavenworth by twenty-seven Members, with thirty-six guests (including twenty-two ladies), and six guests of the Club., viz.:

Frank Allen and wife.
Kenneth Allen.
Dr. and Mrs. F. B. Tiffany.
D. Bontecou.
W. H. Breithaupt.
V. H. Hewes.
A. N. Connett.
John Donnelly and wife.
C. M. Duncan.
F. C. Florance.
J. Brown.
J. Walker.
J. H. Grove.
H. F. Hill.
W. D. Jenkins, wife and daughter.
H. W. Kerr and wife.
Wm. B. Knight and wife.
Miss Frye.
G. K. Musselman.
A. Potter.
Wm. Mendenhall.
Miss Olcutt.
Miss Vreeland.
G. W. Pearsons, wife and two daughters.
E. J. Remillon.
J. Norris.
E. W. Stern and two ladies.
F. W. Tuttle and wife.
F. B. Tuttle and Miss Dodds.
M. N. Wells.
V. M. Witmer and Miss Reynolds.
C. E. Taylor and two Misses Danaker.
T. F. Wynne and wife.
F. Callahan.
Glen. Miller.
M. Hoffelt.
F. L. Miller.

GUESTS OF THE CLUB.

Gen. H. F. Devol.
S. H. Yonge.
T. C. Bradley.
F. Matthews.
Edwin Walters.
A. C. Stites.

Leaving the Wood Street Station of the K. C., W. & N. W. R'y by special train at 10 A. M., the party was first taken to the Soldiers' Home at Leavenworth, where they were met by Gov. A. J. Smith, of the Home, and his wife, Maj. W. B. Shockley, Adj. Gen. Robt. Hayes, Lt. Chas. Moore, Chief Surg. Dr. Weaver, Asst. Surg. Dr. McNary, and the engineer of the Home, Mr. Johns, and were joined by Mr. and Mrs. A. J. Tullock and Mr. and Mrs. Geo. T. Nelles, of Leavenworth. The dining hall was visited first, where 1,080 veterans marched in, seated themselves and began eating on the tap of the bell, to be followed by nearly as many more. The absolute cleanliness of the hall and kitchen was remarked with pleasure. On the

second floor was found a large hall with stage, seats and altar, to be used as theatre, ball room or church (Catholic or Protestant) as occasion requires. The ladies rested on a piazza in front commanding a fine view of the surrounding country while the gentlemen interested looked about the grounds.

Returning to the depot, the Leavenworth Rapid Transit Railway, through the kindness of Mr. Nelles, its Chief Engineer, carried the party by special train to the city, where an elaborate lunch was tendered at the Delmonico Hotel by Mr. Tullock, President of the Missouri Valley Bridge and Iron Works. Mr. Breithaupt proposed a vote of thanks to Mr. Tullock, which was unanimously accorded.

President Knight then called on Mayor Neely, of Leavenworth, who responded in a speech of welcome, and was followed by General Devol, who made a few remarks suitable to the time and place.

The new Union depot was opened for the occasion, and a serious delay avoided by the kind offer from the Union Pacific Railway of the use of their tracks to the fort.

Stopping at the shaft of the Leavenworth Coal Co., Superintendent J. E. Carr took the party over the works, and at the water-works the superintendent, Mr. Hastings, conducted them through the pump house and the electric light station near by.

At the fort carriages were in waiting to convey the ladies up the bluff. It being Saturday, there was no military display; but, as at the Soldiers' Home, excellent music was furnished by the band. Captain Knight, Department Engineer, with several other officers, met and entertained the party.

Returning to the station at about 6, a camera was in waiting to take views of the party, after which the train was taken back to Kansas City, arriving at about 9 o'clock, after a most enjoyable day.

KENNETH ALLEN,
Secretary.

MONTANA SOCIETY OF CIVIL ENGINEERS.

JULY 21, 1888:—A regular meeting was held at the office of Mr. E. H. Beckler, Chief Engineer Montana Central Railway, at 7:30 P. M., Second Vice-President Beckler in the chair. There were present: Messrs. E. H. Beckler, Geo. O. Foss, W. W. de Lacy, Chas. W. Helmick, Walter S. Kelley, Hermann Kemna, A. B. Knight, J. S. Keerl, L. R. Lothrop, A. F. Whitcomb and Geo. F. Wickes.

The minutes of the previous meeting were read and approved.

The Secretary read a letter addressed to Gen. B. H. Greene, Chairman of Committee on National Public Works, from Hon. J. K. Toole, Delegate in Congress for Montana, acknowledging the receipt of the Memorial to Congress from this Society, praying for the re-organization of the National Public Works. He stated that the Memorial had been duly presented, and assures the Society of being entirely in sympathy with its object and purposes.

A communication from Mr. C. L. Strobel, Chairman of the Committee on Highway Bridges of the Western Society of Engineers, was read relative to the Report of that Committee, looking to "Bridge Reform," and containing a request for an expression of opinion by this Society upon the subject matter of said report, and asking answers to the following questions:

"1. Do you favor the appointment of a State Engineer?

"2. Do you consider it desirable for bridge engineers to adopt a scale of minimum rates for preparing working plans and specifications for bridges?

"3. Are you willing to co-operate with this Society by the appointment of a committee to consider and report on the subject of a scale of minimum rates?"

On motion of Mr. Foss, the Secretary was instructed to transmit the matter contained in said communication to each member of the Society, with the request

that they forward their views in time to be canvassed at the meeting of August 18th next, that the meeting may act in accord with the Society's opinion.

Mr. Foss, Chairman of the Committee on Topics, made a verbal report upon the progress of business in the hands of that Committee.

The question of the relative effective powers produced by a locomotive when pulling and backing was proposed and discussed at considerable length by Messrs. Beckler, Kelley, Knight and Wickes.

The Chairman recited a number of novel features introduced in laying track on the Montana Central Railway, and suggested the subject to the Committee on Topics as being probably a proper one for a paper assignment.

A general discussion followed upon the Wickes Tunnel, 6,170 feet long, in course of construction on the line of the Montana Central Railway, the completion of which is put down for the middle of September.

General discussions were entered into upon railroad trestles and upon the use of five rails on 16-degree and 18-degree curves on standard gauge.

Adjourned to meet at same time and place August 18, 1888.

J. S. KEERL, Secretary.

ASSOCIATION OF ENGINEERING SOCIETIES.
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THE PLANT OF THE BOSTON HEATING COMPANY.

By A. V. Abbot, Chief Engineer of the National Superheated Water Company, of New York.

[Read before the Boston Society of Civil Engineers, November 16, 1887.]

A few days ago one of the local papers facetiously remarked that "the citizens had, during the past few months, a good chance to examine all the subsoil of the Boston streets, for within that time nearly every cubic inch of it had been frequently exposed to view." Now I am glad to have an opportunity of explaining to the scientific portion of Boston why some of this exposition of the subsoil has taken place, not with the view of mitigating any of the trouble or inconvenience that has been experienced, but to enable you to draw on your imaginations and to consider some of the advantages that will be derived in the future.

If Herbert Spencer had written upon the evolution of a city, I think that he would have remarked that the line of progress was from the individual to the corporation. In the small village each man has his cow, his well, his kerosene lamp and his wood pile; in the city we have milkmen, a gas company, the municipal water-works, and, we hope to have very soon a heating plant. Strangely, nearly every domestic want excepting that of heat has been already supplied in the larger cities from corporate institutions.

In a few places attempts have been made to introduce some means of delivering heat from a central station. Probably Pittsburgh, from the advantages derived from the almost inexhaustible supply of natural gas which there exists, has made a more widespread success in this direction than any other place. From the gas wells in the vicinity of that city an enormous supply of natural gas can readily be obtained at a pressure sufficient to force it many miles from its source, and to distribute it to all consumers. Obviously, very few places have such natural advantages, and some other means must be devised if it is desired to furnish heat in a location not supplied with gas wells. Several plants have been introduced to deliver heat by means of a number of boilers located at a central station supplying live steam to a series of pipes extending through the streets of the district to be served. The steam thus distributed may be used in any way in the same manner as if it was drawn directly from the boiler itself. Where plants of this kind have been carefully introduced with appropriate engineering skill, and with due precautions against the liabilities to which they are exposed, steam heating has been successful.

Recently another idea has been introduced which, it is believed, will obviate some of the difficulties which attend the use of steam for the distribution of heat on a large scale, and which will enable the necessary plant to be constructed much more cheaply. This system involves the circulation from the boilers of hot water, not of steam.

The object of the heating system is to distribute heat from place to place, and whatever means is used to carry heat from point to point is simply auxiliary, the distribution being the end to be accomplished.

Before we proceed further, we must establish some standard by means of which heat can be measured. If one is to measure milk, the quart is the unit; if land, the acre; if cloth, the yard; and so with heat, a unit is necessary. The unit that is adopted in this country is the quantity necessary to raise a pound of water one degree; strictly I should say that a unit of heat is the quantity of heat necessary to raise a pound of water from 38½ degrees to 39½ degrees, the point of maximum density.

Water was selected as a measure for heat, because it was supposed to have the greatest capacity for heat of any known substance. Now a solution of sugar and element of bromine are found to have slightly greater specific heats. With the unit of heat we can express quantities in terms of that measure—for example, one thousand units of heat is the quantity necessary either to raise a pound of water one thousand degrees or one thousand pounds of water one degree. It is true that the specific heat of water increases slightly as the temperature rises, but that increase is so very small that for anything but the most accurate and exact calculations it may be neglected.

To carry any substance from one point to another we wish to select for our means of transportation that arrangement which will enable us to convey the greatest amount for the least expenditure. If we want to haul a thousand tons of earth, we get the largest cart that the horse can easily draw; if we wish to carry a load of rails, we obtain the largest car that can accommodate them. So, for the transportation of heat, we naturally select that substance which will convey the largest amount of heat. Mercury, oil, steam, hydrogen gas or petroleum could be employed; but, inasmuch as water, per unit of volume, will contain the most heat, it is obvious that it is best adapted as a vehicle. It would be possible for us to use a solution of bromine or sugar, to which I have alluded, but these substances have too slight an advantage in specific heat over that of water to render their use advisable.

Reference to the accompanying illustration, Fig. 1, may aid an understanding of our system. At a central station* a number of boilers are located, exemplified in the illustration at A. From the boiler A proceeds a pipe C' to a pump B. This pipe is attached to the suction end of the pump, and consequently the action of the pump withdraws the water from the boiler. Proceeding from the discharge end of the pump a pipe C extends through the streets, and returning to the central station, enters the boiler at C''. As soon as the pump is set in operation, the water flows out of the boiler by the suction pipe C and is forced around through the streets and back again into the boiler by the pump. If, during its passage, no water is taken from the main, every stroke of

*The plan of station is shown in Fig. 1a.

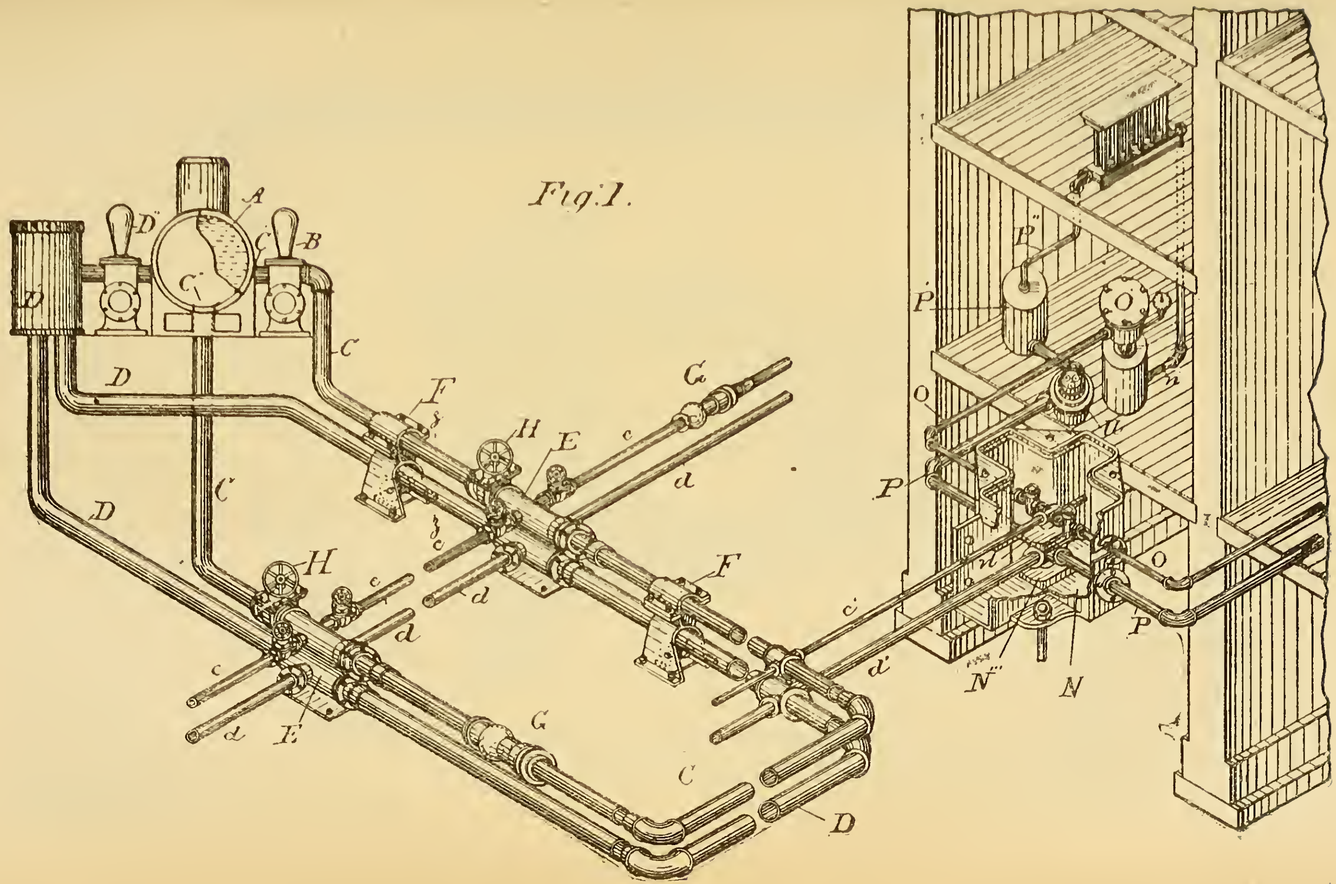


Fig. 1.

the pump withdraws from the boiler and returns to it again an equal quantity of water. In reality the office of the pump *B* is simply to sustain a continuous circulation through the hot water main.

Directly beneath the hot water main *C* there will be seen the pipe *D*, which in the station terminates in the tank *D′*. This second main collects the water as fast as it is used and cooled, and returns it to the sta-

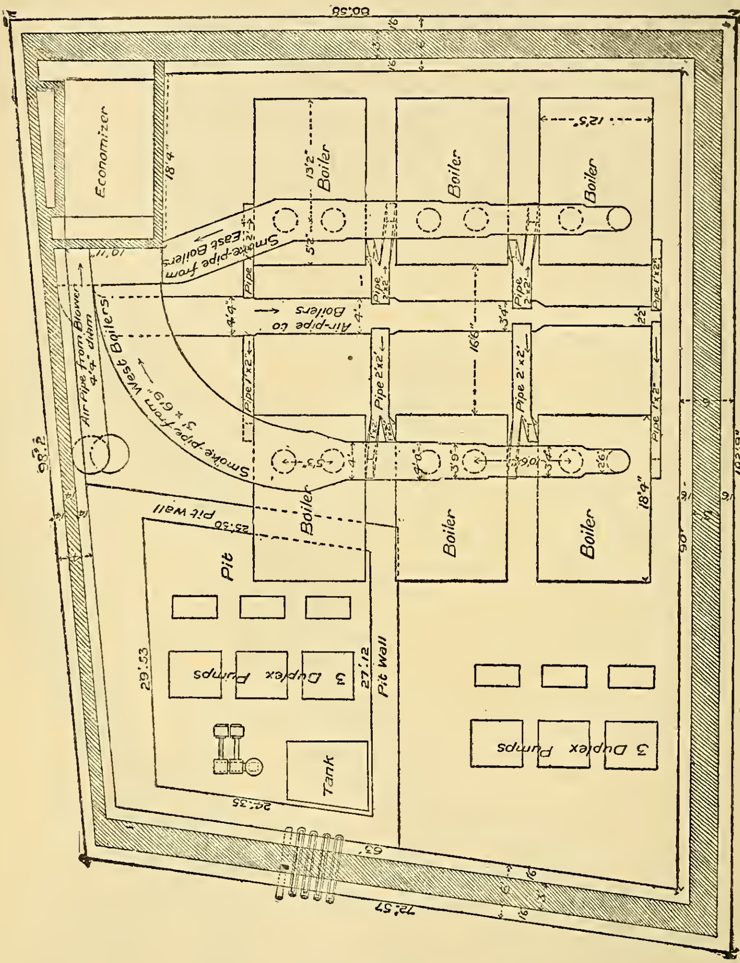


Fig. 1a.

tion, from which function it derives the name of the return main. As the return main empties into the tank *D′* all the water which is cooled and carried back to the station is delivered into this tank, from which a second pump *D″* draws the water and forces it back into the boiler, again to receive a fresh quantity of heat, and to be ready for another journey through the supply main.

From point to point along the supply main small pipes c' extend to the curbstone and terminate in the service box N. The pipe in the service box is so arranged as to enable a single box to supply three houses. This is accomplished by capping the end of the pipe with a three-way tee to which are attached three asbestos cocks. From this tee in the service box small copper pipes O extend into the adjacent houses furnishing them with a supply of hot water. Directly beneath the supply pipe c' is a similar, though larger pipe d', to collect the cooled water from the houses and conduct it to the return main. This pipe d' also enters the service box; and there, by a similar arrangement of tees and cocks, is enabled to receive the water from the three buildings which the hot water pipe directly above supplies.

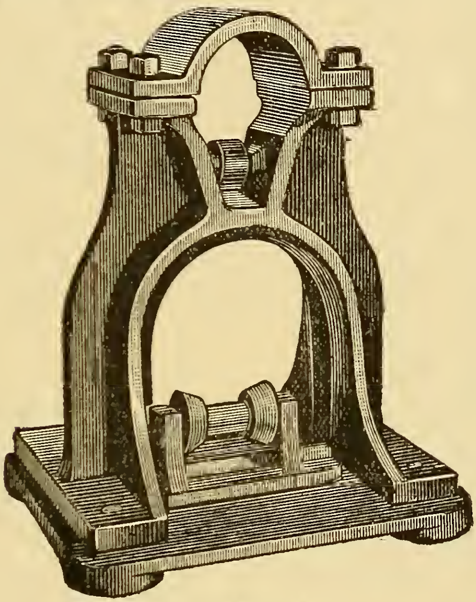


FIG. 2 BRACKET.

At the risk of being a little tautological, I will very briefly go over the circulation again, so as to emphasize the way in which the water passes out of the station, through the streets, and back into it again.

We have a boiler in the station—there may be a single boiler or there may be a large number, depending on the size of the district to be heated. From the boiler the water passes into the suction end of the pump ; from the discharge end it runs through the street and back into the boiler again, maintaining a steady circulation for the purpose of keeping a constant temperature in the supply main. From various points on the supply main small pipes are laid, extending into the houses and stores, from which a quantity of water may be drawn off and used in any way.

After the water is cooled it returns through a second pipe into a second main laid under the first, which returns the cooled water into a tank, from which tank a second pump forces the water back into the boiler again.

In the plant which we have introduced this season the return mains are all laid to grade, so as to conduct all the cooled water to the station by gravity. It is, however, possible to arrange the house appliances, which I shall describe in a few moments, so that they may be capable of returning the water to the station over a higher grade than that at which they are located.

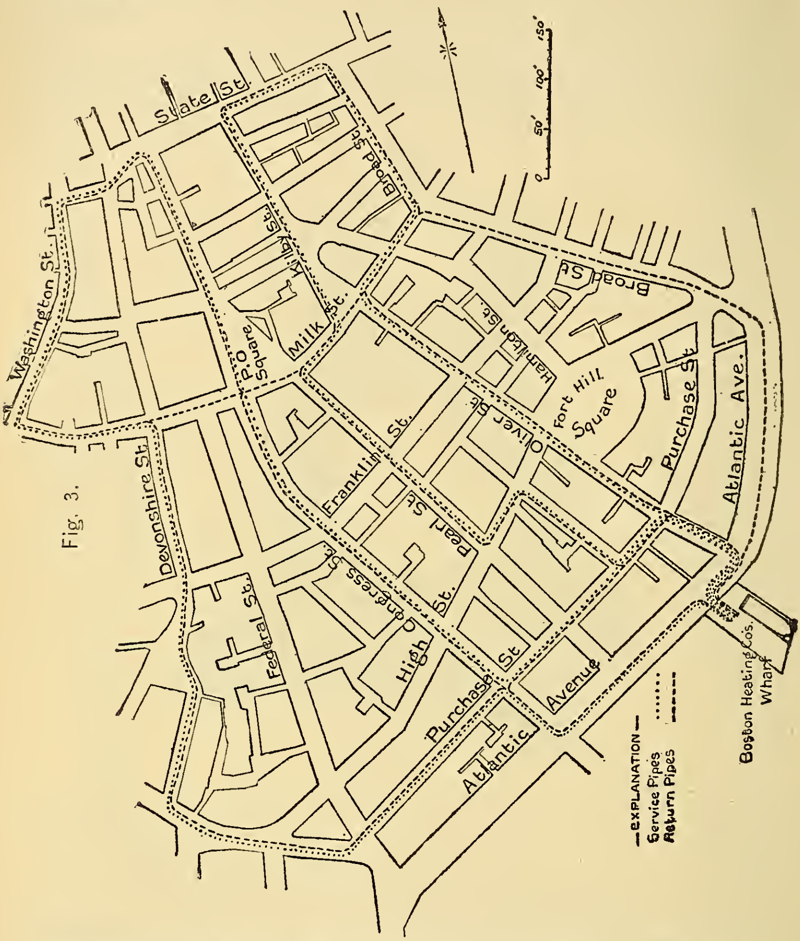
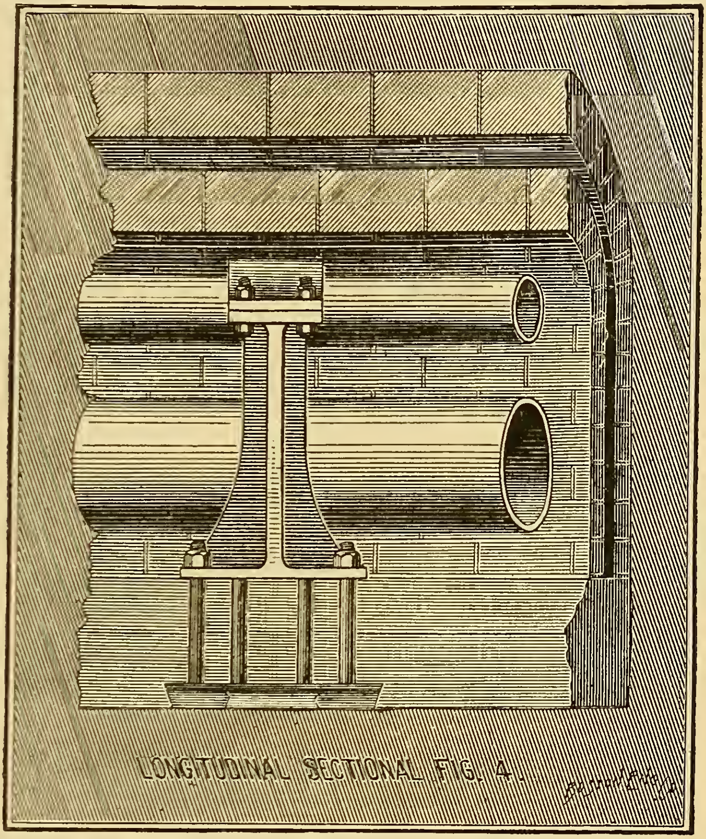


Fig. 3.

Neglecting any slight leaks, unavoidable in so large a plant, and excluding waste that may occur from a thousand and one contingencies, the system, once filled, will always remain full, the water being simply the vehicle by means of which the heat received from the central station is transported to a distance. It is the car in which freight is carried, the water itself having nothing to do but act as a messenger, and after it has left its load of goods it returns to the station to receive another and repeat its journey.

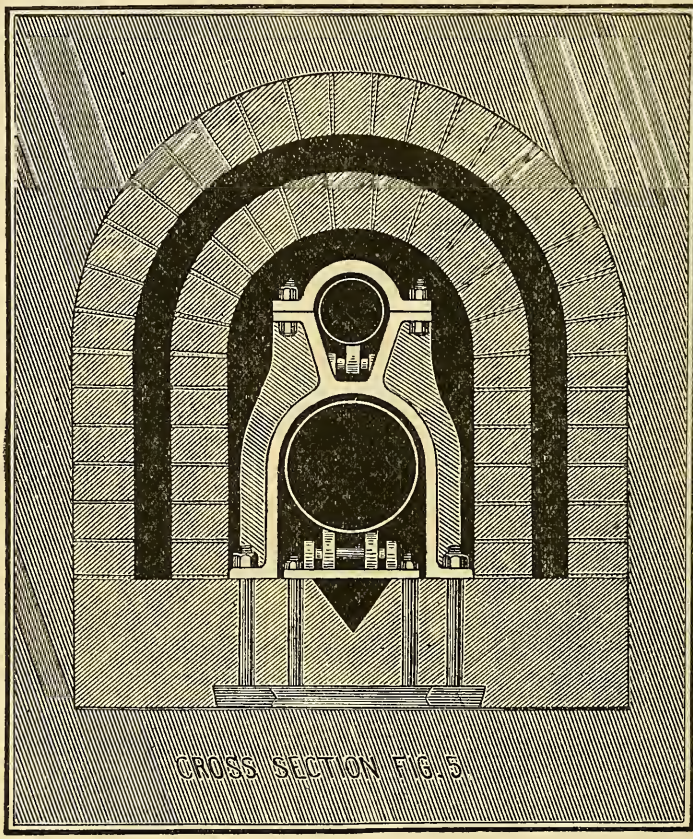
Those who have watched the work in the streets during the past three months have noticed that we have excavated a trench some 2½ or 3 feet wide, and varying in depth from 2½ to 7 or 8 feet, having an average depth of 4 feet. The trench has been excavated to grade between the street corners. Along the bottom of the trench we have spread a uniform layer of concrete 8 inches in thickness made of one part of cement, two parts sand, and two parts broken stone thoroughly rammed into place. Once in about 15 feet a brick pier has been introduced in the concrete and



solidly imbedded therein. On this brick pier has been placed an iron construction called a bracket, Fig. 2.

The bracket consists of a solid, arch-shaped casting supporting a roller covered by a cap. The office of this roller is to carry the four inch supply pipe and allow it sufficient ease of motion so that it may readily expand and contract under the variations in temperature; while the cap surmounting the whole confines the pipe sufficiently in its place so as to maintain it in a fairly straight line and prevent it from becoming in any way displaced. The whole bracket stands on top of the brick

pier, while directly underneath the arch of the bracket a second roller, placed on a small iron stand, is seen, the office of which is to support, in a similar manner, the eight-inch return pipe, and to permit of perfect freedom for expansion. It would seem that there was quite a disproportion between the supply and return pipes. The supply pumps at the station, taking their suction from the boiler, are able to maintain through the small supply pipe a rapid current. We expect to carry a


CROSS SECTION FIG. 5.

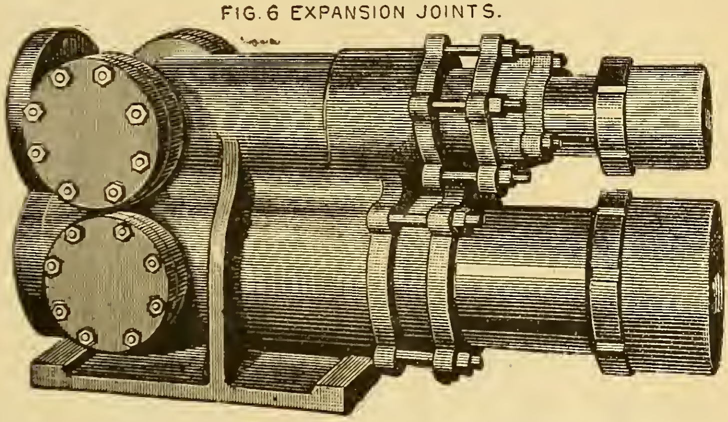
circulation, depending on the demand on the system, of from five to ten feet a second. By means of the pumps, this forced circulation is easily accomplished. While a small pipe for the supply pipe adds to the frictional resistance offered to the pumps, the radiating surface is largely diminished, the cost of the pipe is much decreased and the ease of construction is greatly facilitated. In the return pipe, when the water is to come back to the station by gravitation alone, it is necessary to decrease the frictional resistance as much as possible to afford an abundant chance for the water to run back easily and freely, no matter whether the discharge from the houses is regular or irregular. So we

have for the return pipe an eight-inch pipe and for the supply a four-inch.

The territory covered by our plant is shown on the map, Fig. 3, while the construction of the conduit is illustrated by the longitudinal section, Fig. 4, and transverse section, Fig. 5. In actual steam practice it is found absolutely essential wherever there occurs any change in direction of the pipe line, to introduce some means to provide for the expansion which is due to the variation between the temperature at which the pipe is laid, and that which it attains so soon as circulation takes place. Experiments on various mechanical contrivances have convinced us that the best joint to be used for our purpose is the telescope expansion joint.

The expansion joint (Fig. 6 elevation and Fig. 7 section) consists of a large casting having two longitudinal holes, into which the ends of the supply pipe and return pipe are introduced. At one end of the casting these holes are supplied with threads *E''*, Fig. 7, and the ends of the pipe are screwed into them in the same way that they are introduced

FIG. 6 EXPANSION JOINTS.



into an ordinary coupling. By this means, as the expansion joint is firmly bolted to the masonry foundation, the joint forms an anchorage, so that one end of the section of pipe to which the joint is attached is firmly fixed and held in its place. At the opposite end of the joint from the screw threads, the casting is enlarged so as to receive two sleeves of phosphor-bronze *K*, containing a large percentage of aluminum. These sleeves form the movable part of the joint, and, after being introduced into the casting, are carefully packed with a rope made of pure asbestos fibre, *J*, impregnated with black lead. This packing is introduced between the casting and the phosphor-bronze sleeve in the same manner as ordinary packing is introduced into stuffing-boxes; and the gland *L* is firmly fastened on top of the packing. The outside end of the phosphor-bronze sleeve is furnished with a screw thread *C*, to which the end of the pipe is attached, so that when the pipe expands or contracts, the phosphor-bronze sleeves moves in and out of the casting and accommodates itself to the varying lengths of the

pipe. By means of the gland in the stuffing-box and a corresponding ring *e* on the inside of the casting, the phosphor-bronze sleeve is very carefully aligned, so that its motion in and out is in a straight line. In the joints which we have introduced here, the sleeve of the supply main is long enough to give a motion of 12 inches, while that of the return main is about 8 inches. Inasmuch as these joints are placed, on an average, as often as once in 100 or 150 feet, and the maximum motion

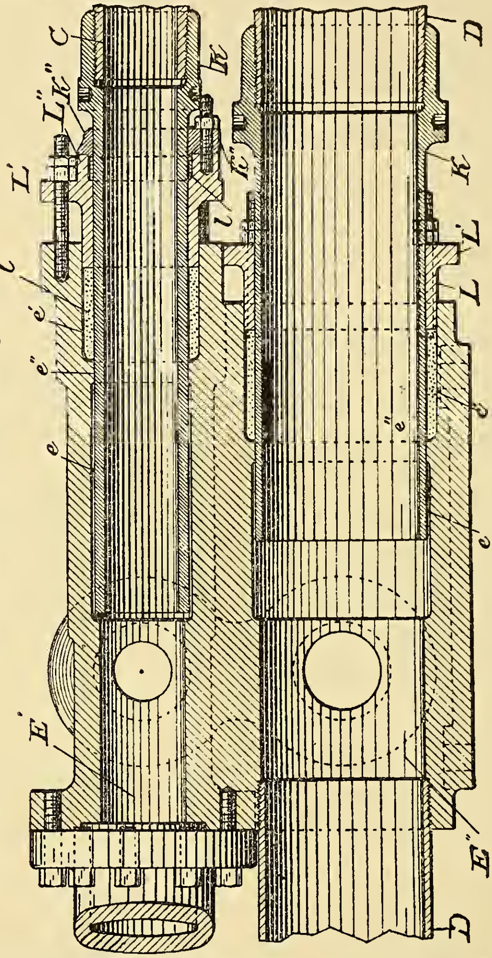


Fig. 7. Section of Expansion joints.

for which they will have to provide being only from 4 to 6 six inches, it will be seen that there is an abundant margin to prevent any possible cramping.

Last spring we built an experimental joint of this kind, and setting it up in our shop in New York, put on a steam pressure of four hundred and fifty pounds to the square inch, and attaching a lever to the sleeve, worked the joint to and fro several thousand times, corresponding to

several thousand expansions and contractions of the pipe. At the end the joint was as tight as it was in the beginning, not leaking a drop.

Each one of the expansion joints is placed in a manhole, so that it is perfectly accessible to inspection or repairs. On the fixed end of the expansion joint there is a valve. The object of this valve is twofold. Beyond the valve, in the casting of the expansion joint; is a side outlet also provided with a valve. In the growth of the system it will soon be necessary to introduce cross pipes extending between the main supply pipes passing through the side streets so as to give a hot water supply to the intervening buildings. For example. there is a manhole at the corner of Devonshire and Franklin streets and one at the corner of Franklin and Congress. At each of these manholes occurs an expansion joint. At any time it is simply necessary to connect this valve at Congress street with the corresponding one at Devonshire street, and then, opening the valves, a stream of hot water would flow between the two streets, making a cross-connection from which the buildings on those streets could be supplied.

When it becomes necessary to repack the expansion joints—though to the best of our belief the packing will last a long time—it is only necessary to shut off the valve at one manhole and a corresponding valve at the next to cut a section of the main out of the circuit; and, by opening a side valve, we can discharge the water contained in the main into the conduit, which is provided with a drain for this purpose, and then, by blowing a stream of air into the manhole, cool it off sufficiently so that the workman can open the gland and introduce a new packing—all in the course of a few hours. It could easily be done at night time when the demand for heat was a minimum.

Many questions have been asked as to the safety of this system—pertinent questions, too, because exaggerated statements have been current as to the pressure which we propose to carry.

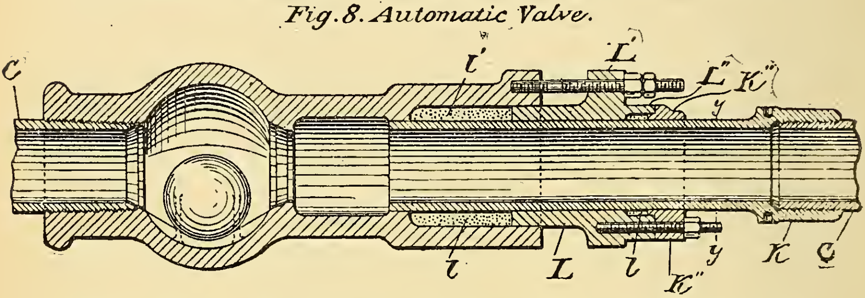
The supply pipe is made of what is called "extra heavy" pipe, the bursting strain of which is twelve thousand pounds to the square inch, as we have ascertained by testing a number of samples to destruction. Every piece of pipe that has gone into the streets has been tested to four thousand pounds to the square inch as a proof test. After the main is laid in place every section—that is, the distance from one expansion joint to the next one—every section, including all screw-threads, all of the packing of the expansion joints and all joints, has been tested to fifteen hundred pounds, and now that the main is completed, we are at the present time making a test of the whole main up to fifteen hundred pounds, from the station round back to the station again. So, when the main is completed and ready for use, it will have received, first, a test at the mill of four thousand pounds; second, a test, by sections, of fifteen hundred pounds, and, third, a test of the main as a whole of fifteen hundred pounds, all being pressures per square inch.

We expect to deliver water to our consumers at a temperature of about four hundred degrees, with corresponds to two hundred and fifty pounds to the square inch absolute, two hundred and thirty-five above the atmosphere. Probably the water will have to leave the station slightly higher than that to provide for the unavoidable radiation. If we send

the water from the station at three hundred pounds to the square inch, and allow one hundred pounds for pumping friction, the total pressure on the main would not exceed four hundred pounds ; and, as the main has been tested to four thousand pounds, there is a larger margin of safety.

As an additional precaution, we have, once in every section, a check valve, so arranged as to shut off automatically each section of the main in case of any accident. Malicious injuries might occur, for it is conceivable that in times of strikes men might dig up the main or drive a pick into it. In the illustration, Fig. 8, a cross-section of this valve is shown in connection with the expansion joint. It will be seen that on the left hand side of the joint the casting is enlarged so as to form a spherical cavity into which one end of the pipe line, C, is screwed in the same manner as into a regular coupling. The spherical cavity contains a ball supported on two ribs so planned as to allow the ball when at rest to remain at the bottom of the cavity. The end of the pipe C is chamfered so as to form a valve seat. Under ordinary

Fig. 8. Automatic Valve.



circumstances, the ball remains at rest on the ribs. Should, however, any rupture occur, the current of water flowing through the main will, by reason of the break, be greatly accelerated, and acting on the ball cause it to roll up along the ribs and seat itself on either side of the spherical cavity toward which the current may be flowing, thus completely shutting off the remainder of the main. The forces keeping the ball in equilibrium are its weight, acting downwards and keeping it in place, and the friction of the water current tending to force it up to the inclined ribs and seat itself against either side of the spherical cavity; so, by varying the weight of the ball, the valve can be adjusted so as to close with almost any desired velocity of current. Under maximum demands, we can use a current of 10 or 15 feet a second, and the ball is so weighted as to close at a velocity of 20 feet a second. Should a rupture in the pipe occur, giving a velocity of 20 feet a second, the ball will leave its place, and, rushing up, close the end of the pipe and shut off the rest of the main. This is not simply theory, but is practice to the extent that we have made a number of these valves, and, after experiment, have found them to work very accurately.

Should any accident occur, either malicious or otherwise, to rupture the main, it is obvious that only the quantity of water contained between two check valves would escape from such a break. As these

valves are placed at intervals of about 100 feet, the amount escaping would not exceed 20 cubic feet. The volume of the conduit is so large that should this entire quantity of water be discharged into it the steam formed therefrom would be quickly dissipated through the length of the conduit without producing sufficient pressure to do any damage.

The conditions which surround a pipe in the street are so different from those to which boilers are subjected, that a little consideration will show an explosion of the pipe to be an impossibility. A boiler, with its setting of masonry and bed of incandescent coal, is encompassed with a highly heated atmosphere which constantly tends to supply it with more and more heat. The street pipe, on the other hand, is *hotter* than its surroundings. On the occurrence of a slight rupture in the shell of a boiler, the pressure is relieved from the large mass of water therein contained and an outflow of the boiler contents established through the incipient opening.

The large diameter of the boiler shell permits the molecules of water flowing towards the incipient rupture to attain, before reaching it, a very high velocity; while the hot masonry surroundings, and especially the glowing coals and incandescent gases of the furnaces, furnish to the water continuous supplies of heat, maintaining the pressure and accelerating the rushing molecules. So, in far less time than it has taken to describe this action, the current of steam and water has attained such velocity that its impact has been sufficient to rend the boiler, and perhaps overthrowing the masonry, hurl it hundreds of feet from its original location. In the street pipe, the comparatively small diameter precludes the possibility of a high velocity in the water current, even should an opening occur. Furthermore, as no supply of heat is furnished to the water, the pipe being surrounded by the comparatively cold conduit every unit of steam formed abstracts and renders latent the heat from five units of water. Thus even if a rupture occurred in the pipe, no disastrous explosive action would follow, a simple tear through which the water would slowly escape into the conduit being the only result.

Before passing to the house connections between the main and the buildings, allow me to call your attention to the special screw thread which we have used in making the joints in the streets with the twofold object of securing extra strength and greater tightness.

Ordinarily, a screw thread, as is well known, reduces the strength of the pipe or rod on which it is cut about 30 per cent. In Fig. 9 the special thread used in our plant is exemplified. The coupling joining the ends of the pipes B and C is made considerably longer than is customary in ordinary pipe fittings. For a little ways the end of the coupling is bored out so as to be a fairly accurate fit on the end of the pipe. This greatly improves the joint, as the over-lapping end of the coupling tends to strengthen and support the pipe that is introduced into it.

The special peculiarity of the thread to which I wish to call your attention, however, is that portion between the points $b\,b'$ and $c\,c'$. It will be seen that the top of the thread is in a straight line with the outside of the pipe, while the bottom of the thread, between the points $b\,b'$ and $c\,c'$, is inclined to the axis of the pipe at a considerable angle, so as to cause it to run out or vanish at b' or c'. By this means the weakening of the

pipe caused by the cutting of the thread is spread out and diffused over a considerable length; and, by proportioning this vanishing of the thread in a proper manner, experiment has

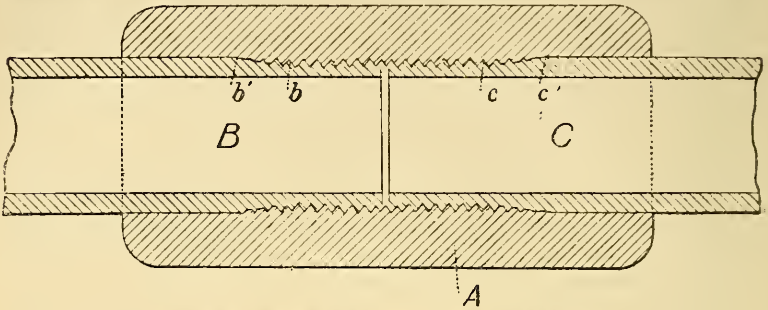
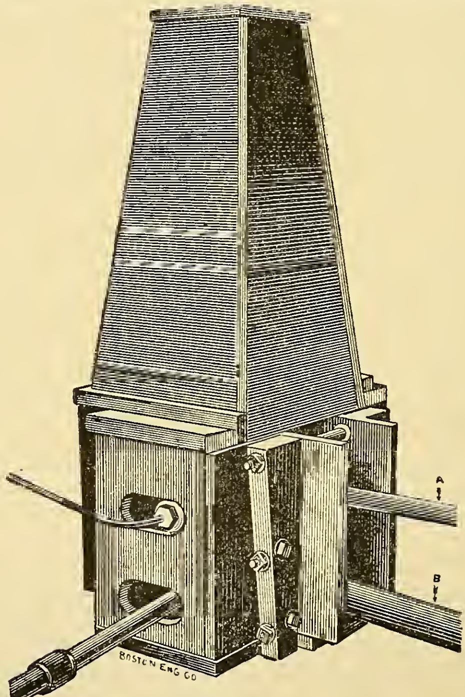


FIG. 9. SPECIAL THREAD.

shown that it has been possible to preserve ninety-seven per cent. of the full strength of the pipe. In addition, this vanishing of the thread produces a long and very tapering cone, which may be



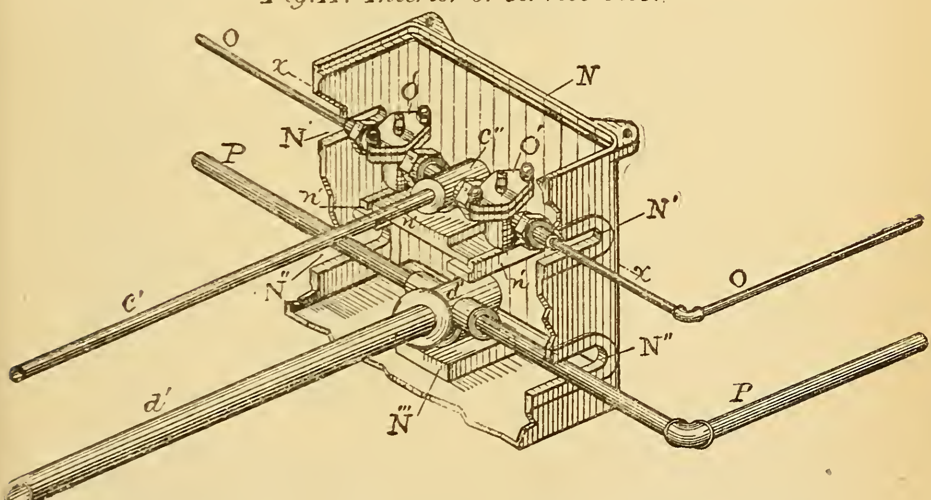
SERVICE BOX

forced into the coupling by means of the pipe tongs in such a way as to actually bed the metal of the pipe into that of the surrounding coupling and make a joint which is absolutely tight. This same result is attained

in a less degree with the ordinary pipe thread, but inasmuch as the cone produced by our special thread is very much smaller angle than that used by standard pipe fittings, the pressure of the tongs in making up the joint causes it to bed more firmly into the metal of the coupling. The rolling mill supplies pipe in lengths of about twenty feet, so that the necessity of securing a perfectly tight connection between each length is very apparent. With this form of thread our experience has demonstrated that, even under 1,500 pounds, it is perfectly possible to secure absolutely tight joints. In testing the sections, we have never found a leak when the joints were properly made.

Each coupling also forms an opportunity for a house connection. On either side of the coupling a boss is cast. For the house supply inch pipe is used, and for the return two-inch pipe, which extends from the main to the sidewalk on either side of the street, passing through a box made of cresoted yellow pine. At the sidewalk a service box (shown in elevation in Fig. 10 and section Fig. 11) is situated. In Fig. 10 the supply pipe may be seen at *A*, while the return pipe is indicated at *B*. These pipes *A* and *B* enter the box and there terminate in a three-way tee provided with asbestos cocks, by means of which the supply from either branch of the tee can be at pleasure controlled. By means of this three-way tee and

Fig. 11. Interior of service box.



its asbestos cocks, each service box is enabled to supply three houses From the service box to the inside of the house wall—usually a distance of not more than eight feet—copper pipe is employed in preference to iron pipe. The advantage of copper pipe in this location is very obvious when it is considered that, owing to the ductility of this metal, the pipe can be bent in any desired shape without the necessity of special fittings, involving the construction and maintenance of a large number of joints. So by using, from the service box to the inside of the house wall, a copper pipe, we are enabled to introduce in it as many bends and carry it around as many corners as may be necessary.

The size of copper pipe which we most frequently used is quarter inch which is amply sufficient to supply ordinary buildings. In the case of large stores or warehouses, three-eighths or one-half inch is employed. While, where it is desired to supply power to an engine of 25 or more horse-power, five-eighths or three-quarter inch pipe is employed. A one-inch pipe, such as you see here, would be ample to supply so large a building as the Post Office. All of these samples of copper pipe which you see here, have been tested to over 6,000 pounds. The sample of one-inch pipe split at 6,200 pounds, while the smaller size held 7,000 without showing any signs of failure.

The water, as I have already shown, is merely the vehicle for the transportation of heat. And now having indicated the method by which we introduce it inside a customer's wall, the question arises, how can it be used?

Very broadly, it may be stated that our service is perfectly adequate to afford a supply of heat for any purpose whatsoever requiring a temperature of 400 degrees or less, whether it be for heating, power, cooking, chemical operations, or any branch of manufacturing. The various appliances, however, by means of which the heat contained in the water may be utilized, are as varied as the different branches to which it may be applied.

For heating simply two plans present themselves. Hot water can be introduced directly into a radiator, which may occupy the same position that the present furnace in the house takes up, and may warm a quantity of cold air supplied through the cold air box, and send that air heated through the flues that are already in place, so as to warm the building in the same way that the furnace does at the present time, only substituting a hot watercoil for the glowing mass of incandescent coal.

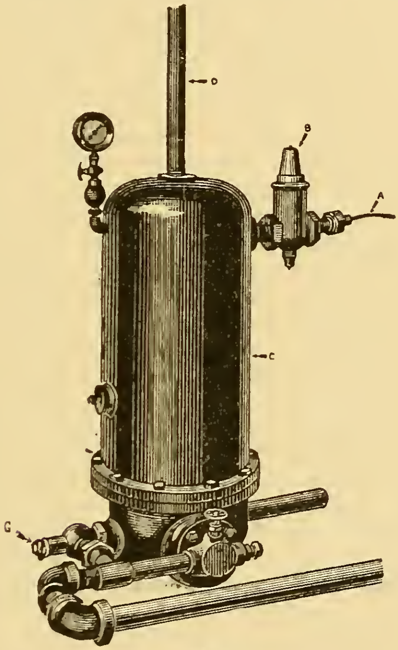
Where the edifice is already piped for steam, or in case of a set of offices where a very varied supply is desired, steam heating in the usual manner may be resorted to by the introduction of a device called a "converter." This contrivance, shown in Fig. 12, may be very briefly described as a steam dome, for in reality in our system it occupies the same place that a steam dome does in a boiler. If, in imagination, you will conceive an ordinary boiler to be stretched out so as to occupy two miles of space, you will have a very fair conception of our system as applied to the distribution of steam heat.

The end of the copper pipe *A* as it comes in from the street is attached to a reducing valve *B*. This reducing valve we make of rather peculiar construction, so as to specially adapt it to withstand the pressure to which it is subjected and also to afford a regulator of unusual sensitiveness and durability. By means of the pressure reducing valve, most of the pressure on the water contained in the copper pipe is removed and the water allowed to flow into a large iron receptacle *C*, which forms the steam dome proper. By the removal of the pressure a part of the water is thereby permitted to take up the superfluous heat and to expand into steam.

On the left-hand side of the converter a small steam gauge is shown, the purpose of which is to constantly record the pressure to which the

converter is subjected, and to enable the reducing valve to be set so as to give a pressure of any desired amount. In the top of the converter a steam pipe *B* conveys the steam away as fast as it is formed, and carries it to any part of the building where its use may be desired. At the bottom of the converter a return pipe *E* may be seen connected to a float-trap placed on the inside of the converter. Another pipe *F* is used to convey back to the converter the condensed water from all of the radiators, so that there may be little or no loss in the system. As fast as this condensed water accumulates in the converter the trap previously alluded to discharges the water from the return main *E*, and allows it to flow into the main in the street, whence it is conducted to the station.

As a precautionary measure, a safety valve *G* is attached to the con-



THE CONVERTER

verter so that in case of any failure of the reducing valve to act in a proper manner, which might possibly allow a greater pressure to come on the converter than is intended, this safety valve will open and permit the contents of the converter to flow into the return main, and relieve itself entirely.

For supplying steam to an engine no change is made in the converter excepting to enlarge it sufficiently so that there may be a sufficient quantity of steam always on hand ready to supply the cylinder of the engine. We generally calculate that, to preserve an adequate supply, it would be necessary to have the volume of the converter at least ten times that of the cylinder of the engine which it is designed to feed. So, for a large engine, we merely increase the size of the iron dome to such propor-

tions as shall always preserve the requisite amount. For any cases where both heat and power are desired in the same building, as frequently occurs, we use a compound converter with two reducing valves so arranged that the water first introduced from the street shall expand into one chamber, giving, for example, a pressure of 60 pounds of steam for the purpose of driving an engine. As soon as the water, under the pressure of 60 pounds, is discharged from this first chamber in the converter, by means of the trap, it is received in a second one where, by means of an additional reducing valve, the pressure is again reduced and the remaining portion of heat contained in the water allowed to expand a part of it into steam, which may be used for heating. By this means we are enabled to reduce the temperature of the water to the greatest amount, thereby returning it to the station as cool as possible.

In a system of this kind protection from radiation is an exceedingly important consideration. After a number of exhaustive experiments on nearly all of the non-conducting coverings now in use, we decided to adopt a covering made of asbestos. The covering is simply a roll of pure asbestos fibre 1½ inches thick. It is made by taking the asbestos from the mines, carding it in the same way that cotton wool is carded, and winding it around a cylindrical roll. After the mixture is dry a saw is run along the side of the roll, cutting the covering in two; then the roll is opened and it is taken off. On the outside of the asbestos is a solidly woven cloth made of asbestos rendered waterproof by an admixture of plaster of Paris, and held in place by wire netting.

Returning for a moment to the section of conduit, Fig. 5, we have in the centre the pipe itself; outside of the pipe an inch and a half of asbestos with a water-proof asbestos covering. An air space of 4 inches separates the asbestos from the first brick arch, then a second air space of 2 inches and a second brick arch. So we think the system is about as thoroughly protected from radiation as could be done. As to the insulating power of the asbestos this experiment may be interesting:

I had an air-bath made, so arranged that it could be kept at a constant temperature of 500 degrees Fahr. A sheet of the asbestos covering, just as you see it, was laid on top of the air-bath. In contact with the upper side of the asbestos a piece of 2-inch yellow pine plank was placed so as to cover the sheet entirely. Between the asbestos and the plank a second registering thermometer was introduced, so that the temperature between the asbestos and the plank could be accurately ascertained. The experiment was continued for several days, during which time the air-bath was constantly maintained at a temperature of 500 degrees, and the highest temperature ascertained as occurring between the asbestos and the wood was 158.

The relative cost of transporting heat from point to point is a most important consideration. Suppose that it is wished to maintain at any place a constant temperature. It may be a radiator for steam heating, or a cook stove or steam engine. If we have a vessel in which we wish to maintain a constant temperature, it is necessary to supply the heating medium to that vessel at a higher temperature than that at which it is to be sustained, and the greatest economy of maintenance is only achieved by supplying the medium to the vessel at the highest possible temperature

and exhausting it therefrom at the lowest. In other words, to furnish the least quantity of the circulating medium with the greatest possible fall in the temperature. If we supply a pound of water, we will say at 400 degrees, and let it cool down to 200, we get 200 units of heat; if we supply it at 300 and allow it to cool down to 200 we get only 100 units of heat. So that in the practical operation of a system of this kind the aim should be to introduce the circulating medium at the highest temperature and reduce it to the lowest. The temperature required for cooking is about 350 degrees, and it is probable that this demand is the most severe that can be made on the system; and for a discussion of the relative advantages of water over steam as a medium for the transmission of heat, I have selected this as being the one that would present the system in its worst light.

If a range is to be maintained at a temperature of 350 degrees, it is proposed to supply water at 400 degrees. Suppose there is introduced into the range a cubic foot of water at 400 degrees. The weight of the cubic foot of water is 53.63 pounds. If the temperature of the range is to be kept at 350 degrees the water can only be allowed to fall 350 degrees. The fall in temperature is, therefore, 50 degrees. The whole quantity of heat liberated by the fall of the water is 53.63 times 50 times 1.0174 or 2,728 ($53.63 \times 50 \times 1.0174 = 2728$) heat units.

The medium which is most commonly used instead of water for the transmission of heat is steam. Supposing, instead of admitting to the vessel a cubic foot of water we admit therein a cubic foot of steam at the same temperature of 400 degrees. That cubic foot of steam weighs .547 pounds. Now, if that steam falls from 400 to 350, a portion of the steam is condensed and the latent heat liberated. A cubic foot of steam at 400 degrees weighs .547 pounds, and at 350 degrees it weighs .3056 pounds, the difference between the two is .24 pounds. The latent heat of evaporation of steam at 400 degrees is about 830 units per pound, therefore by multiplying 830 by .24 we obtain a product of 199.2 as the number of heat units set free by the fall in temperature of a cubic foot of steam from 400 to 350 degrees. It has been seen that the cubic foot of water will deliver 2,728 units of heat, while the cubic foot of steam yields 199. The ratio of these two quantities is 1 to 13.7.

Hence it is obvious that 13.7 cubic feet of steam must be circulated to do the same amount of heating as may be accomplished by 1 cubic foot of water. Just as soon as the steam has fallen to the temperature at which it is required to maintain the range, the steam must then be exhausted to give rise to a new supply. It is true that steam being a light, aeriform fluid, will flow through pipes more easily than water will.

By the well known laws of hydraulics, the relative velocities at which fluids travel through pipes vary inversely as the square root of the densities. The relative density of water to steam is as 1 to 9.87. Consequently, under the same conditions, with the same length of pipe, the same resistances in the pipe, and the same pressure on the circulating medium, 9.87 cubic feet of steam would flow to 1 cubic foot of water. But the water is to the steam, as far as heat carrying power is concerned, as 1 is to 13.57; whereas the relative quantities which

would be transmitted through a pipe are as 1 to 9.87. The expense of delivering to a distant point any fluid depends simply upon the amount of mechanical work necessary to overcome the resistance of the pipe. The relative velocities at which water or steam will flow are as 1 to 9.87; but the relative quantities necessary to deliver the same quantity of heat are as 1 to 13.7, hence the current of steam must have a velocity of .135 times that necessary for the water current. Remember that the transmission through a pipe is not a question of weight, but a question of volumes. A 4-inch pipe will carry no more cubic feet of mercury than it will of hydrogen gas, although the density of the mercury is several thousand times that of the hydrogen. It will carry more pounds of mercury, but no more cubic feet. So to deliver equal quantities of heat there must be in the case of steam a velocity of about .135 times that of the water. The mechanical work, which is the measure of the expense of transportation of a fluid, varies as the cube of the velocities at which the fluid flows. We have seen that under similar circumstances if the velocity of the water current is 1, the velocity of the steam current to transmit an equal amount of heat must be 1 and 35. Cubing, it is obvious that the relative expense of transporting equal quantities of heat by steam or water will be as 1 to 2½.

It is usually assumed that a current of steam flowing through a pipe is maintained by the expansive force in the steam itself. Precisely; but this expansive force in the steam is only attained by a fall in pressure and temperature, and consequently by a corresponding amount of condensation.

Returning to our former example, if, at the end of a long line of pipe, it is wished to deliver steam at a temperature of 400 degrees, corresponding to a pressure of 250 pounds to the square inch, it would be necessary at the central station to put upon the boilers a sufficient pressure in addition to that at which it is expected to deliver steam to overcome the inevitable friction of the pipe between the boilers and the place where the steam is to be received. In a long line this friction is of considerable amount, so that in order to accomplish the necessary delivery of steam the boilers would be called upon to bear a burden equal to the amount of radiation of the line plus the amount of frictional resistance offered to the steam current. The frictional resistance may of course be reduced to a minimum by the use, in line, of pipes of very large diameter. This has frequently been done, with the inevitable result of very largely enhancing the cost of the plant and increasing the difficulties both of construbtion and maintenance.

In the case of the water plant, it is only necessary to subject the boilers to the pressure requisite to give the temperature at which it is wished to deliver the water plus the much smaller amount of radiation which takes place from a pipe of less diameter than that employed in the steam plant, the frictional resistance of the pipe being entirely overcome by means of the forced circulation obtained by the pump. The boilers, which perhaps are the most difficult part of the system, being entirely relieved from this extra pressure, are much more easily constructed and maintained. Thus by means by the use of an incomprehsible fluid like

water, and the employment of a pump to produce circulation, a much higher initial pressure can be placed upon the pipe line to overcome the frictional resistances of the pipe, thus enabling us to employ a very much smaller pipe than is customary to use in steam plants, and largely decreases the expense of the system and the difficulties of construction and maintenance.

Even to engineers too much mathematics is provocative of a certain kind of madness, which I am fearful my insipid figures may have already induced. Alas! that I have not the brush of an artist or the tongue of an orator to adequately depict for you the future which we believe will grow from the germ that last summer, 'mid trouble, confusion and annoyance, we have planted in the subsoil of the Boston streets.

We dream of a tropical future from which dust, ashes and smoke are banished; of chimney-less houses, from the cellars of which the black diamonds of the present are exiled, giving place to paper and paint, and becoming habitable.

We dream of matrons made happy by the absence of dust, on whose carpets no particle of ashes ever lights; and yet whose houses are as balmy as the air of the tropics; whose range is never cold; whose ovens never refuse to bake; nor is the good man's wrath ever provoked by the tardy breakfast, the fault of the over-sleeping domestic; for, Lo! in an instant, by a touch on a valve, the range glows with heat, and winter or summer, early or late, the ovens, at a constant and equable temperature, never refuse to fulfill their duty on the minute.

Who knows! Ten years ago, when the first squeaky voice pulsated across Machinery Hall, Boston little dreamed that now it could talk to Chicago. In comparison with the electrical wonders of the past decade, our most sanguine expectations seem easy of realization; and when achieved, Boston may again take to herself the credit, as she has often done in the past, of being the successful pioneer in a new field.

FEBRUARY 10, 1888.

POSTSCRIPT.—The main and station of the Boston Heating Company was completed and in readiness to commence circulation about the middle of December. The pipe line, after being tested from the station round to the station again, was thoroughly washed out to remove all dirt and grease, by pumping water through it for two days. The main was then connected with a battery of boilers of 200 horse-power, underneath which a slow wood fire was started, so as to gradually heat the water contained in the boilers. A steady circulation was at the same time maintained through the whole of the main, so that as fast as the water was warmed in the boilers, it might be sent out into the main, thus gradually heating the whole system.

About ten day was consumed in warming the main up to the temperature of about 380 degrees. During this time the whole line was carefully watched to ascertain whether any leakage developed, and whether the expansion joints worked in a proper manner. No trouble of any kind was experienced, the main under heat being found to be ully as tight as it was under cold water pressure. All of the expansion oints operated as had been antici ated, taking up the expansion, as the

temperature increased, in a perfectly satisfactory manner. After the temperature of 380 degrees was attained, a solution of potash was pumped into the mains and circulated for several days in order to remove all grease and red lead, so that the system would be full of clean water. After two or three days' circulation of potash water, the main was cleaned by allowing the hot potash water to escape, and replacing it in the boiler with fresh warm water. This cleansing of the main was continued until the water showed no signs of potash or grease.

After this thorough cleansing had taken place, the various consumers, whose house connections had been made, were, one after another, turned on to the line, and at the present time the company is heating about twenty-five large buildings and supplying power to some engines.

So far all the consumers on the line have expressed complete satisfaction with the service rendered to them. Experiments on the losses by radiation show that the steam furnished is exceptionally dry. One engine is run from an exposed pipe over 60 feet from the converter, and no trouble whatsoever is experienced with water in the cylinder, showing that even when the steam is exposed to this amount of radiation it is as dry as steam furnished by ordinary boilers.

STADIA MEASUREMENTS.

By James Ritchie, Member of the Civil Engineers' Club of Cleveland.

[Read February 28, 1888.]

Stadia measurements were first used in 1820 by an Italian engineer. In 1836 they were used in the topographical and military survey of Switzerland, and in 1850 they were introduced in this country by Mr. J. R. Mayer, a civil engineer, who brought the method from Switzerland.

It is not necessary to go into the theory of stadia measurements except so far as will show the fundamental principles of the same. The accompanying demonstration is taken from J. B. Johnson's work on "Transit and Stadia."

Let $L\ S$ (Fig. 1) be the objective lens of the telescope, F the position of an image for parallel rays, that is of an object at an infinite distance. Let C be the centre of the instrument, or the intersection of the plumb line (extended) with the axis of the telescope. Let E_1 and E_2 be the "principal points" and let the distance $F\ E_1 = f$ (the focal length), and $\left.\begin{cases} I\ E_1 = f_1 \\ O\ E_2 = f_2 \end{cases}\right\}$ confugate foci. Let $A_1\ B_1 = i$—for image—intercepted portion and $A_2\ B_2 = s$—for stadia—intercepted portion.

Since $A_1\ E_1$ is parallel to $A_2\ E_2$ and $B_1\ E_1$ to $B_2\ E_2$ we have $A_1\ B_1 : A_2\ B_2 : : I\ E_1 : O\ E_2$ or $i : s : : f_1 : f_2$ (1). Also from the law of lenses $\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{f}$ (2). Since the distance $F\ E_1 = f$ is constant for any lens or fixed combination of lenses, we see from (2) that if the object approaches the lens the distance f_2 is diminished and f_1 is increased. If the extreme wires in the telescope be supposed to be placed at $A_1\ B_1$ in the figure, then $A_1\ E_1\ B_1$ is the visual angle and is equal to $A_2\ E_2\ B_2$.

But as the image changes its distance from the objective as the object is nearer to or farther from the objective, the distance $I E_1 = f_1$ is variable while $A_1 B_1$ is constant for fixed wires. Therefore the visual angles at E_1 and E_2 are variable. If these angles were constant the space intercepted on the rod and the distance of the rod from the objective would

Fig 1.

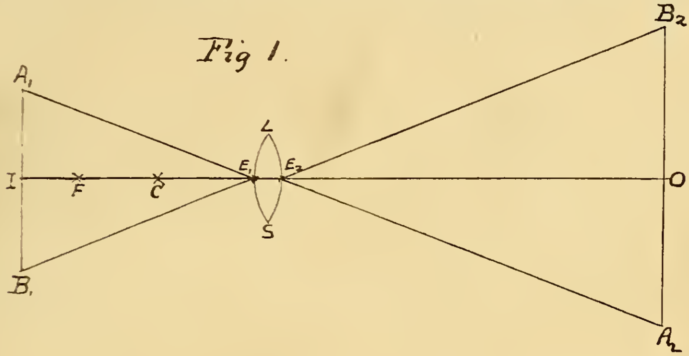
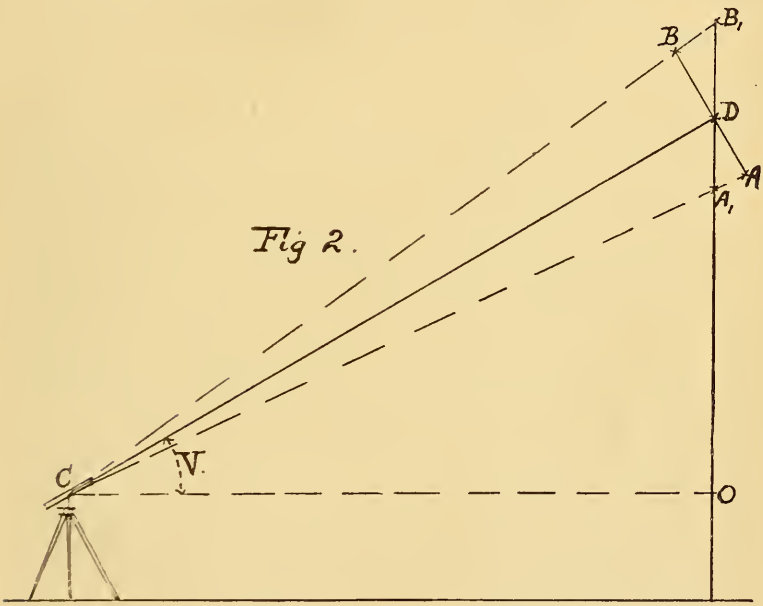


Fig 2.



be in constant ratio. This is not the case, however, and the relation between the distance $O E_2$ and the space $A_2 B_2$ on the rod may be found as follows :

From equation (1) we have $\frac{1}{f_1} = \frac{s}{i f_2}$ and from equation (2) $\frac{1}{f_1} = \frac{1}{f} - \frac{1}{f_2}$ Hence, $\frac{1}{f} - \frac{1}{f_2} = \frac{s}{i f_2}$, or, $f_2 = \frac{f}{i} s + f$. That is, the

distance of the rod from the objective is equal to the intercepted space s multiplied by the constant $\frac{f}{i}$, plus the constant f, where f is the focal length and i is the distance between the extreme wires.

If the distance is to be reckoned from the centre of the instrument, as is customary, let this distance $= d$, and the distance from the centre of the instrument to the objective $= c$ ($C\ E_2$ in the figure), then $d = f_2 + c = \frac{f}{i}\ s + f + c$.

To find the constants f, i and c we first measure the distance from the centre of the instrument to the objective, which gives the value of c; then focus the objective on some distant object, as far distant as possible, and measure the distance from the plane of the cross wires to the objective, which will give the value of f; then setting up the instrument, measure forward a distance $= f + c$ as already found, and from this point thus obtained, measure forward a base line of any convenient length. Hold the rod at the extremity of this base and measure the space intercepted by the extreme cross wires. Call the length of the base $= b$ and the intercepted space $= s$, then $b = \frac{f}{i}\ s$, or $i = \frac{s}{b} f$. If it is desired that $\frac{s}{b}$ should equal $\frac{1}{100}$ (as is customary), then the wires must be apart a distance $i = \frac{1}{100} f$.

Stadia rods are graduated to suit the instrument with which they are to be used, but ordinary level rods may be used, care being taken to add the constants ($f + c$) to the distance given by the rod. In graduating the stadia rods there are various methods used for obtaining accurate results, but the method used most generally is as follows: A base line is measured, whose length should be that of the average sight it is desired to take. The instrument being set at one end of the base, the rod is held at the other, and the intercepted distance on the rod is marked and then divided up as finely as it is desired to take the readings, and the divisions extended to the limits of the rod. This rod is only absolutely correct for the same distance at which it was graduated, but may be used without sensible error for longer or shorter distances.

In making surveys with the stadia it is considered best to use an inverting telescope, as the great point is to be able to see clearly and distinctly the symbols on the rod; and the direct telescope, requiring the use of an additional lens, does not have as clear a field as the inverted. The telescope should have a vertical circle attached firmly to the axis, and it should be in perfect adjustment, as the accuracy of the results depends largely upon the correct use of the vertical circle. The horizonta circle should be graduated one way from 0° to 360°. It is customary to start from a known bearing or azimuth, and continue the main line of the survey by azimuths until some other known point is reached from which a check upon the bearing may be obtained.

Whenever a sight is taken for a stadia measurement, the horizontal angle or azimuth, the vertical angle and the distance, must be read and

recorded. The main line should have the stadia rod and the vertical angle read on the backward sight, as well as the forward, in order to check the work. The sketches in the note-book should show clearly the general outline and features of the country and the location of each stadia measurement.

The field work of a stadia survey may be done very rapidly and with sufficient accuracy for any topographical work, as well as for preliminary surveys of railroad lines, provided in the latter case that it is not desired to make an estimate of cost of construction, in which case I should prefer the chain survey, followed by an accurate line of levels. The stadia is often as reliable for elevations as an ordinary line of levels would be, but I should not like to trust entirely to its accuracy, but should accompany it with a flying level party to check each main point. The distances measured by the stadia are the actual distances between the instrument and the rod, and must be corrected by multiplying by the cosine of the vertical angle. Also, there is another correction due to the rod being held in a vertical position instead of being perpendicular to the line of sight.

Let $A\ B$ (Fig. 2) represent a rod held perpendicular to the line of sight $C\ D$, and let $A_1\ B_1$ be a rod held vertical, then the angle $A\ D\ A_1 = D\ C\ O = V$, the vertical angle. Then $A\ B = A_1\ B_1 \cos V$, and $C\ D = \frac{f}{i}\ A_1\ B_1 \cos V + f + c$. But the distance $C\ O$ is what is desired, hence we have $C\ O = C\ D \cos V = \frac{f}{i} A_1\ B_1, \cos^2 V + (f + c) \cos V$, and the difference of elevation $O\ D = C\ D \sin V = \frac{f}{i}\ A_1\ B_1, \cos V \sin V + (f + c) \sin V$.

From these formulæ tables have been calculated giving the horizontal distance and difference of elevation for each minute of vertical arc for 100 feet slant distance. With these tables the correct horizontal and vertical distances can be rapidly computed from the field notes and plotted on the map.

Stadia measurements are used by the United States Coast and Geodetic Survey, by the United States Lake Survey and the Mississippi River Commission in completing their topographical surveys, but they are always used in connection with a careful system of triangulation and check levels. In obtaining the outline of river banks, islands, sand bars, or in location of contour lines, I should use the stadia in preference to any other method. As to accuracy of closing, I have run lines along the bank of the Mississippi River from one triangulation point to another, a distance of about 10 miles, and not varied in closing on the second triangulation point more than two meters, that is about 1 in 8,000, which is certainly nearer than it could have been chained. But in making that survey we did not need to use the vertical circle, as the river banks did not vary over three or four feet in elevation in the whole distance. The longest sight taken was 830 meters and was taken from a projecting point of the bank to a similar point, avoiding what would have required two days solid labor to have crossed with a chain, namely, a thicket of young cottonwoods and creeping vines, mingled with fallen

trees, logs and driftwood. In such work there is nothing equal to the stadia for rapidity and accuracy.

In land surveying over rough country or through low brushwood where it would require cutting to use a chain the stadia can be used to advantage. In moderately level country it is full as easy to use the chain. In city work, where great accuracy is required, or in the measurement and staking off of allotments, the stadia is, in my opinion, of no use. Nor could it be used advantageously in locating points whose distances are known, such as staking out a railroad location, setting slope stakes, etc., for the reason that to lay off a distance by stadia requires that the vertical angle shall be known, whereas, we must first fix the point in order to find that vertical angle.

The stadia was used in connection with the plane table, by which some of the most elegant and accurate maps of the Coast Survey have been made. Among the other departments of the government engineers the plane table has been almost entirely superseded by the stadia for filling in the topography of a trigonometrical survey.

In making a preliminary survey for a railroad through very rough country, it would be very easy for an engineer, with three rodmen, to make good progress, and the result would be a reasonably accurate contour map of the region through which it were desired to run the line. But in order that a careful estimate of cost be made, a certain line should be located through said region which should be limited to the grade and curvature desired for the traffic. This would necessitate making a location on the map and calculating from the contours the profile of the desired line. And when this were done your line might or might not come within the limits of grade. In such a case I should, as stated before, prefer to run a chain survey with profile and flying levels, keeping my line where the flying levels showed the desired elevation. With a stadia survey, one does not know anything about his grade unless he should begin at the beginning of his notes and figure up the same from the distances and vertical angles. The same is true of his horizontal distances, unless his measurements have been on quite level ground, when the slant distances will very nearly agree with the horizontal. A vertical angle of 1° 46′ makes a difference of 0.1 foot in 100′ in horizontal distance, and a difference of 3′.08 in elevation, according to Professor Johnson's tables, but a vertical angle of twice the size (3° 32′) gives a difference of 0.38 foot in 100′ in horizontal and 6′.15 in elevation, showing that the differences of elevation vary nearly as the angle varies, but that the horizontal difference varies almost as the square of the angle. However, the contour map, if wide enough to plot the line upon under the required grades and curvature, is a very useful factor in the location of a railroad line.

A WELL VENTILATED MINE.

By Lewis Stockett, Member of the Engineers' Club of St. Louis.

[Read May 16, 1888.]

The ventilation of a mine is such a simple matter that I have often thought its very simplicity was one of the great reasons why it is so often neglected, and that if it was a more complex subject, requiring great learn-

ing generally and deep study locally, those who have the matter in charge would be more apt to give it the proper attention that it deserves. The ventilation of a mine consists in passing a current of pure air of sufficient volume through the mine and around the working faces to so dilute all gases, etc., given off as to render them harmless, and mixing in with the air current be passed out of the mine. This is the whole secret of mine ventilation, and to carry it out it is first necessary to have the means of making the air current, and then this having been secured to see that it is properly carried through the mine to the face of workings and wherever needed.

In order to pass an air current through it is necessary that a mine have at least two openings, one for an inlet and the other for an outlet. The current is produced by the difference in density and consequent difference in weight of the air in these two openings. This difference is made by various means, among which are the furnace, steam jet, water fall, steam coil and mechanical ventilators; it is also produced to some extent by the warmer lighter air of the mine being pressed out by the colder heavier air of the atmosphere (in warm weather the action being reversed) producing natural ventilation. Of these the furnace and mechanical ventilators are the ones most in use at present, and the most effective, and in this country the centrifugal ventilator commonly known as the fan is most generally used, for the reason that few of our mine openings are of sufficient depth to make the furnace the more effective.

The difference in pressure of the air in the inlet and outlet necessary to produce a current is so little that it can only be readily measured by the water gauge, which will show the pressure by the difference in height of two columns of water, connected together at the bottom, the upper end of one column being introduced into the air current and the upper end of the other open to the atmosphere. A difference of one to two inches, or from 5.2 pounds to 10.4 pounds per square foot, is sufficient, if the air shaft and air courses are of sufficient size to pass the current and the fan of sufficient size to allow the current to get through it.

Fans are of two general types, the vacuum and plenum, or exhaust and pressure blower, and of each of these types there are almost innumerable forms of construction, as there should be to meet the different duties to be performed in different localities. Of the two general types the plenum or pressure blower is the more effective; this can be proved by a mathematical demonstration and corroborated by actual experience.

By whatever means the air current is produced it is worthless if not properly distributed and carried without loss to where it is needed. This is where the greatest number of failures in ventilation are found, the superintendent, mining engineer, or other in charge considering their duty done in having provided the means of creating the air current and entirely neglecting to see that it is properly taken care of after secured. To properly conduct the current through the mine it is necessary that the mine be opened with that object in view, remembering that an air current requires a return as well as an intake. This is best accomplished by driving all entries in pairs and frequently cross-cutting. If the ventilation of the mine requires such a volume of air as to make the velocity so great as to be an inconvenience to those working

therein, three entries should be driven, and by using one as the inlet and two as the outlet (or *vice versa*), the velocity on the two entries will be about one-half, and on these two entries the work of the mine should be carried on, using the other for an air course alone. This can also be accomplished when there are several districts in a mine by taking a split or portion of the current into each district and not passing the full current around through the whole mine, which will also have the important effect of increasing the amount of air by decreasing the total amount of friction and the velocity at which it travels.

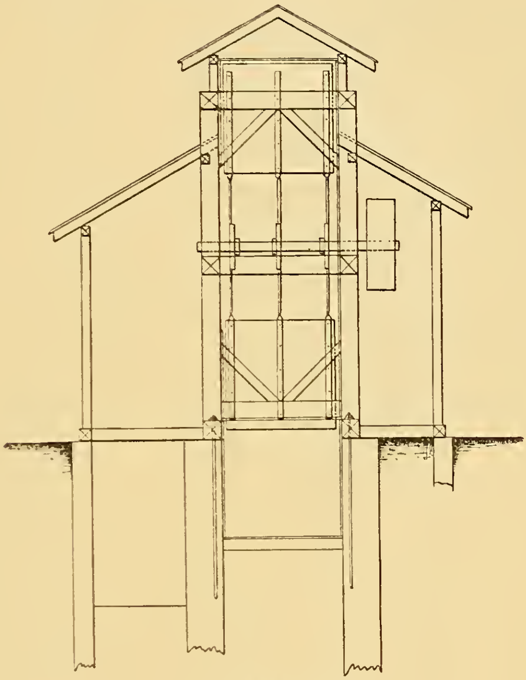
In splitting the air into separate currents, care must be taken that this is not carried to an extreme, and the volume of each current so reduced as to be unable to perform the work required of it.

In passing the air up one entry and down the other of a pair of entries, the frequent cross-cuttings alluded to above are a great source of loss of air through leaks in the stoppings put up in these cross-cuts to throw the air on to the last one opened. It is frequently found that where the air current is more than sufficient at the mouth of the entries, at the face where it is most needed it was very weak or had entirely disappeared. Little leaks all along the line, trifling in themselves but disastrous as a total, were the cause; and where the workings of one district hole through into those of another district is generally found a source of waste. To prevent this every cross-cut should be closed as soon as the one ahead is opened by an air-tight stopping which can only be securely and permanently done by being built of rock or brick laid up in lime and sand or cement mortar, and these occasionally plastered over. And to prevent the leaks from one district to another, where workings have holed through, rooms, breasts, stopes, etc, should be closed up as soon as finished and which will also prevent the gases from old workings escaping into and vitiating the air current.

Doors, curtains, regulators and brattices are used to direct the air current and throw it where it is needed, as to the face of headings, up through working rooms, etc., and when used for this purpose only are very useful in their way. Main air currents should never be separated by a door if it is at all possible to do otherwise; overcasts in the top or undercasts in the bottom, either of timber, rock, or brick are much better, and while the first cost is in excess, the wages of a door tender or trapper saved, soon make them the cheaper. If for local reasons overcasts or undercasts are impossible and the door must be used, two doors sufficiently far apart that in passing through them one can be closed before the other is opened, will prevent the loss of air from the opening of the door and reduce the amount of leakage.

Where the hoisting shaft is one of the openings for ventilation the air current is considerably checked by the cages moving up and down in the shaft; where large hoists are made it takes but little calculation to show that fully one-half of the time of working hours the cages are in the shaft and form a barrier to the air current at the time it is most needed. For this reason a separate compartment in shaft or another opening is essential. When the entries in the mine are small in area, a trip of loaded cars, if moving against the current or more slowly than and with the current, form a very serious barrier to the air, and in mines venti-

lated by only one main current almost stops the flow; to overcome this, whenever possible, the entries or headings should be driven larger than is simply required for the roadway. When the current is in several splits this blocking of the air by trips of cars is not so serious a matter, for if one split be blocked it will increase the volume in another, and it rarely happens that all are blocked at the same moment.



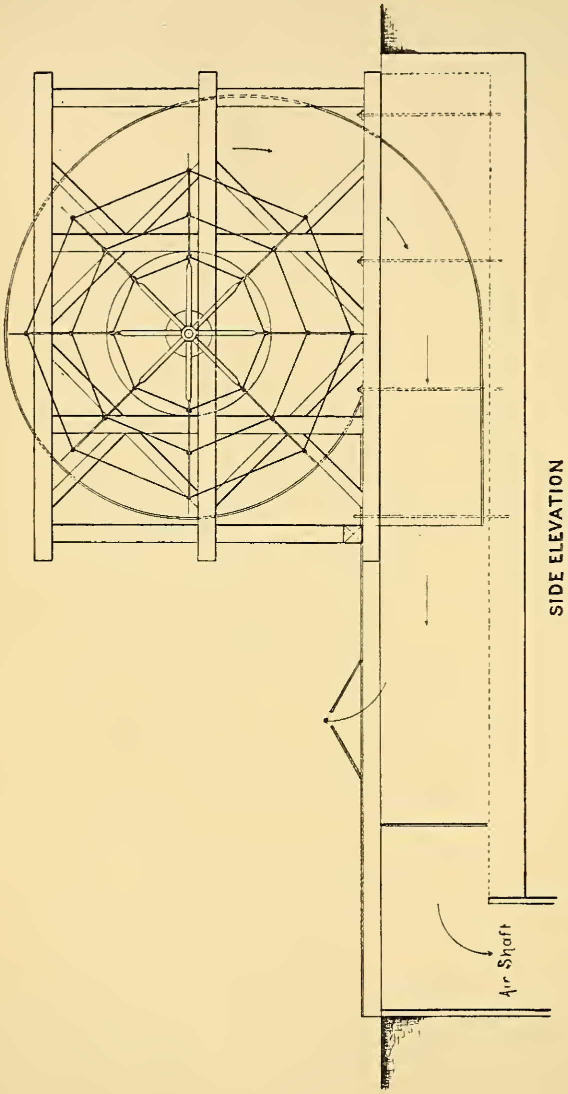
END ELEVATION

20 FT. FAN — NO. 6 MINE

[illegible]— ENGINEER.

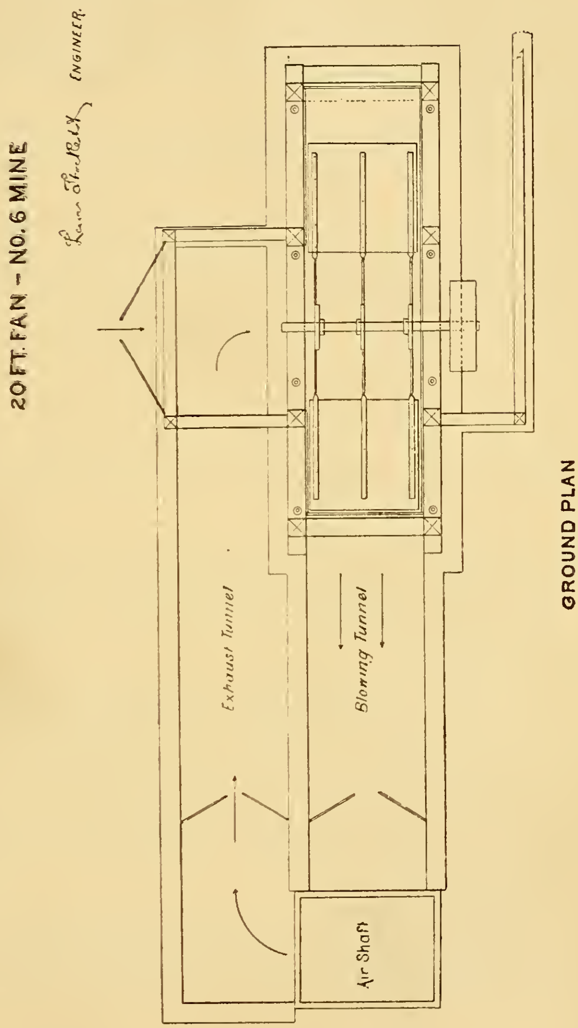
The value of compressed air as a ventilator is made much of by those interested in introducing mining machinery to be driven by compressed air, but when we consider that it is a very large sized compressor that compresses 5,000 cu. ft. of free air per minute, and that this small amount is scattered in very small parts all over the mine and is used irregularly, we can put this factor down for nothing as regards the ventilation of the mine, and as less than nothing if it leads one to suppose that it is ventilating his mine and causes him to neglect other means of ventilation.

In a dry, dusty mine, where the air is constantly filled with floating particles of dust, explosions are likely to and have taken place from the



ignition of the same from an overcharged blast or the firing of some small body of gas. With a proper air current these particles will be carried off, but in some cases it is only overcome by sprinkling the roads

with water from water cars. These cars are arranged with a pump driven by a crank on the axle of the wheels, which will throw water through a hose and enable the top, sides and that part of the bottom distant from the road to be wet down.



Having thus covered the ground somewhat generally, it is part of this paper to present a practical illustration of a mine where the details of thorough ventilation have been well carried out, show the mode of so doing and give the results obtained.

The mine in question is known as Mine No. 6, and is situated on the Wabash, St. Louis & Pacific Railway, near Staunton, Macoupin Co., Ill. The current is produced by a 20 feet in diameter centrifugal ventilator, located at the head of an air shaft $5' \times 8'$, and driven by an engine whose cylinder is $18'' \times 42''$, connected to the fan by a belt. The fan making one and one-half revolutions to one of the engine; the usual speed is 60 for the engine and 90 for the fan; some idea of this speed can be had when it is known that at 90 revolutions the end of the blades are traveling 5654 feet, over a mile a minute, and exceeding the speed of the fastest railroad train.

The fan is so built that it can be readily and quickly changed from an exhaust to a pressure blower, and is so constructed that in all its relations it is equal whichever way it is used. The accompanying drawings will explain this.

The air current is divided into nine separate splits, the volume of each split being regulated to the amount of work being done in each district. This reduces the friction, the great destroyer of an air current, to a minimum, thereby increasing the amount of the air passing, and also reduces the velocity on hauling roads so that a naked lamp can be carried with ease.

Overcasts and undercasts are used wherever they can be to advantage, there being seven in number, and their location is shown by the accompanying map.

The stoppings between main and return currents are mostly of brick and lime and sand mortar, or built up of rock from the roof plastered over.

Old workings have been completely stopped off by brick and mortar stoppings, and the large amount of black damp given off from old gobs kept out of the current. Air courses where not used, as hauling roads have been cleaned up and the area enlarged to pass the current readily without excessive friction.

Further improvements in contemplation and under way are the driving of a main air course to another mine, to make use of an abandoned shaft for the second opening, and overcome the obstruction of the cages in the shaft before spoken of, and enable the escapement ladders and platforms in air shaft to be removed. These ladders and platforms in the air-shaft are a very serious obstruction to the air current, and account for the high water gauge. After these are removed there will be a larger volume of air at the same expenditure of power, or an equal volume at a less expenditure.

The fan running at 90 revolutions as a pressure blower gives a water gauge of $2\frac{1}{10}$ inches, and as the same number of revolutions as an exhaust gives $1\frac{8}{10}$ inches, which will bear out the statement before made that the pressure blower is the more effective as compared with the exhaust fan.

As a pressure blower the fan running free to the open air gave a water gauge of $\frac{9}{10}$ of an inch and a volume of 240,000′ of air. With the outlet blocked up the water gauge was $2\frac{5}{10}$ inches or 13 pounds to the square foot for the pressure blower, and $2\frac{1}{10}$ inches for the exhaust fan.


Ventilation Plan
STAUNTON No.6 MINE
Scale
OLD WORKINGS
OLD WORKINGS
Note
Stoppings
Doors
Overcasts
Direction of Air Current
Split of Air Current
Junction of Air Currents

W[illegible] the fan running at 86 revolutions the following measurements of [illegible]e of the air were made :

[illegible]		air under fan			76,636	feet.
	[illegible]	E. main split	35,100	feet.		
		W. " "	40,920	"	76,020	"
	[illegible]	E. return	36,450	"		
"	"	W. "	44,250	"	80,700	"
"	"	E. No. 1 split	12,870	"		
"	"	" " 2 "	6,875	"		
"	"	" " 3 "	10,800	"		
"	"	" " 4 "	4,320	"	34,865	"
"	"	W. No. 1 "	6,000	"		
"	"	" " 2 "	11,550	"		
"	"	" " 3 "	10,125	"		
"	"	" " 4 "	8,482	"		
"	"	" " 5 "	1,692	"	37,849	"

The figures, while good of themselves, will be greatly increased when the improvements named above are finished and the job complete.

SHEET OR ASPHALT PAVEMENTS.

At a meeting of the Civil Engineers' Club of Cleveland, April 10, 1888, Capt. D. Torrey, of New York, read a paper in favor of sheet or asphalt pavements compared with stone. The following discussion took place :

Mr. Morse said that sheet pavements were fine pavements if they could be made to last, but that the cost of keeping them in repair was very great.

Mr. Richardson asked if information could not be obtained from London, Paris, Washington and other cities with regard to the durability of these pavements and cost of repair.

Captain Torry stated that on some of the streets of London that ran from ten to six times the tonnage per foot of width of Superior street in Cleveland, the sheet pavement had been found economical. Leadenhall street in London has never been renewed, but repairs have been made. The oldest pavement of this kind in America has been in use twelve years. The asphalt apparently is not worn at all.

Mr. Richardson said that he had been informed that in Paris small depressions were at once filled up. They were not allowed to grow large.

Mr. Baker asked whether repairs were made in these London pavements by the contractors or by the municipal authorities.

Captain Torry said that the repairs were sometimes made by the authorities and that sometimes the contractors offered to keep the pavements in repair for a term of years. In Washington repairs are made twice a year, spring and fall. The city of Washington makes a contract for repair twice a year for a five years' guarantee. It costs thirty-three and a third cents per foot—three dollars per yard.

Mr. Morse asked how much it would cost for a guarantee of ten years.

Captain Torry said that after five years the contractors would agree to repair for ten cents a yard for a long term of years. That includes renewals. The pavement never wears out. A pavement that has been down twelve years is said to be good for twelve years yet. A record

taken from Fifteenth street, in front of the Treasury building, showed the daily average of vehicle tonnage to be 66 tons per square foot. The tonnage on Pennsylvania avenue must be between 40 and 50 tons per day. The tables will show that there is little traffic on the streets of Cleveland except with light weight vehicles.

Mr. Whitelaw asked if new covering could be put on old asphalt pavements.

Captain Torry said that he had never seen this done, but that the asphalt can be easily separated or peeled off from the concrete. If any one could discover a way of warming it up without burning so as to separate, it might be used again.

Mr. Whitelaw said that he supposed that when the asphalt was entirely worn out, the surface might be entirely renewed.

Mr. Morse said that it had been stated that the pavement between Erie and Perry street was much worn. It was not so much worn, but it was uneven in consequence of being taken up to lay water pipes.

Mr. Richardson stated that the St. Paul's Church people protested against the asphalt pavement being taken up and stone laid.

A Voice : There is 75 per cent. of coal tar in that pavement in front of St. Paul's Church.

Mr. Morse said that in some of our light traffic streets a stone pavement would last fifty years. He did not know any sheet pavement that would last half that time.

Mr. Whitelaw said that River street was the first street laid with Medina stone. It was laid in 1857, and he thought the stone would be good to take up and lay again.

Mr. N. B. Wood said that in this discussion no account had been taken of the loss of life of horses and destruction of vehicles. In considering the question of economy of pavement that would last fifty years, it should be asked how many horses has it killed and how many vehicles has it worn out.

Mr. Morse said that it would be difficult to answer that question correctly.

A Voice : Would Captain Torry give as nearly as he can the amount of tonnage carried per square foot per day by the oldest Trinidad asphalt pavement and compare that with the tonnage of the viaduct?

Captain Torry said that a street paved with asphalt in Philadelphia carries 142 tons per square foot per day; that is, about three and a half times the tonnage of Superior street and about four times that of the viaduct. The pavement of Superior street viaduct will have to be taken up and reset before it has carried the amount of the tonnage of the street in Philadelphia.

Mr. Morse said that the stone pavement on the viaduct was laid in the all. It was expected that it would settle, and it has settled.

A Voice: I disagree with Mr. Morse with regard to the inequalities of the pavement over the viaduct being due to settlement. They are caused by the horses' hoofs chipping off the edges of the blocks.

Mr. Morse said that the gentleman was a little mistaken. Blocks of stone in the railroad track were worn turtle back, but in other places the pavement was worn smooth.

Mr. Baker said that the convenience of persons who were taxed on the abutted property should be considered.

A Member stated that he had recently interviewed a number of people in Buffalo and found that the persons who wanted most the Trinidad asphalt pavement were those who had to pay for it. They desired to have it on account of its beneficial effect on their property.

Mr. Wood said that it was claimed for the Nicholson pavement that it increased the value of property, but people thought differently when it had to be renewed.

Captain Torry said that a great deal of wood pavement was in use in London and Paris. In Paris a large amount of work has been done, and a man has made a contract to take care of the pavement for twenty years. Sometimes as high as a dollar per square yard is paid. In London wooden pavements are put down and renewed as soon as they begin to be a little uneven. To keep asphalt pavement perfectly clean and in good repair for ever would cost about 40 cents per foot of property. On an average street in Cleveland it should cost a man who lives on a 40 foot lot about $16 per year.

Mr. Morse said that if all the streets in the city were paved and were all paid for out of the general fund it would be well, but the pavement was a tax on the adjoining property.

Mr. Strong said that he would guarantee the pavement on Willson avenue for fifty years. Any depressions there have been caused by the taking up of sewers, etc.

Captain Torry said that there was no such trouble with asphalt. It could be taken up and relaid so that there would be no mark on the street. Like a patch on plaster, it can be put on so that the place cannot be discovered.

ASSOCIATION OF ENGINEERING SOCIETIES.

PROCEEDINGS.

BOSTON SOCIETY OF CIVIL ENGINEERS.

SEPTEMBER 19, 1888:—A regular meeting was held at the Society's rooms, Boston & Albany Railroad station, Boston, at 7.30 P. M., President FitzGerald in the chair. Forty-eight Members and nine visitors present.

The record of the last meeting was read and approved.

Messrs. Louville Curtis and William M. Scanlan were elected Members of the Society.

The following were proposed for membership:

Mr. Charles W. S. Seymour, of Hingham, Mass., recommended by M. M. Tidd and W. S. Brown, and Edgar P. Sellew, of Somerville, Mass., recommended by Sidney Smith and G. A. Kimball.

On motion of Mr. Howe, it was voted: That the Secretary be requested to acknowledge, in the name of the Society, its great appreciation of the many kind attentions received from the following parties on the occasion of the excursion to Providence and Newport.

The Old Colony Railroad Company and General Manager J. R. Kendrick, for transportation and special car; City Engineer Samuel M. Gray, of Providence, for the very interesting exhibition of the public works under his charge; Captain Joseph P. Cotton, of Newport, and City Engineer Henry A. Bentley, of Newport, for their untiring efforts to make the visit to Newport enjoyable; Colonel Henry W. Closson, Commandant at Fort Adams, and the other officers of the Fourth Artillery, U. S. Army; Commander C. F. Goodrich, U. S. Navy. Commandant Torpedo Station, and Commander F. L. Higginson, U. S. Navy, Commandant Training Station, and the other officers of those stations for their courtesy to us.

The President read a letter from Mr. Henry E. Waite, of West Newton, presenting to the Society a "Kosmic" clock, which he had caused to be hung on the wall of the Society's room. On motion of Mr. Clarke, the Secretary was directed to suitably acknowledge its acceptance.

The Secretary read a circular from the Board of Direction of the American Society of Civil Engineers, containing an offer to send the Transactions of that Society "to any subscriber at the rate $10 per year, and to clubs of ten or more, when ordered through the secretary of an engineering or technical society or club, who will be responsible for the payment, at 25 per cent. discount." Members of this Society who desired to avail themselves of the offer were requested to communicate with the Secretary at once.

The committee appointed at the last meeting to consider the communications from the Engineers' Club of Kansas City and the Western Society of Engineers submitted the following report:

BOSTON, Sept. 19, 1888.

To the Boston Society of Civil Engineers:

The Committee to whom was referred the appended communications* from the Engineers' Club of Kansas City and from the Committee on Highway Bridges of the Western Society of Engineers, respectfully report as follows:

First, That your Committee is unanimously of the opinion that this Society

* See Proceedings of Engineers' Club of Kansas City, May, 1888, JOURNAL, page 183, and Proceedings of Western Society of Engineers, June, 1888, JOURNAL, page 225.

should proceed very cautiously in the matter of recommending any legislative action which would result in state inspection of highway bridges, as it does not yet appear certain that this method in itself would secure the building of proper structures.

Second, That we do not recommend that the Society take any action in reference to establishing rates for the professional services of civil engineers.

Third, While your Committee dissent as above stated from the methods of action proposed in the communications referred to, we recommend that this Society take appropriate action on the subject of the improvement of highway bridges and appoint a committee to consider and report what legislative or other action would be advisable, and to what extent it would be practicable to co-operate with other societies in this matter.

(*Signed*) JOHN E. CHENEY,
D. H. ANDREWS,
EDWARD S. SHAW.

The report was accepted, and on motion of Mr. Brooks the same Committee was reappointed to carry out the recommendations of the report.

Prof. Dwight Porter then read a paper on the "Removal of Roof Water," which was discussed by Messrs. Cheney, Clarke, Knapp, Olmsted and Smith.

Mr. J. Pickering Putnam, Architect, of Boston, was then introduced, and read a paper on "House Drainage." The paper was discussed at length by Col. Geo. E. Waring, Jr., of Newport, and Messrs. Clarke, Knapp, McClintock, Noyes and Smith, of the Society.

[*Adjourned.*] S. E. TINKHAM, Secretary.

WESTERN SOCIETY OF ENGINEERS.

SEPTEMBER 5, 1888:—The 250th meeting was held, Vice-President John W. Weston in the chair.

The minutes of the last meeting were read and approved.

Mr. Henry S. Maddock, proposed at last meeting, was elected to membership.

From the reports of the Secretary and Treasurer, the following financial exhibit is compiled: Receipts since last meeting, $136.50; cash on hand, $88.32; bills paid, $202.90; bills unpaid, $0; bills reported, $30.

Mr. Weston, from the Committee upon Memoirs of Messrs. Baker and Latimer, submitted a report which was ordered printed. Committee discharged.

The Secretary was instructed to forward paper with discussions, upon Classification of Material in Railway Construction, for publication.

The report of Committee on Employment, as printed in Proceedings for July, was made the special order for the next meeting. It is desired that Members who cannot be present should send in any discussion or suggestion before that date.

Mr. Rossiter called attention to the desirability of a translucent profile paper, suitable for blue printing, and thought that great improvement could be made in the standard papers used by engineers so as to adapt them to such use. The question was discussed at some length, and the general utility of other scales than those furnished was suggested. The following Committee was appointed to consider and report: Messrs. Rossiter, Williams and Parkhurst.

The Secretary read a paper by Mr. Geo. Y. Wisner, upon "Levels of the Lakes as Affected by the Proposed Lake Michigan and Mississippi Water-Way," and a discussion by himself. The matter was discussed by Messrs. Williams, Artingstall, Weston and others. The paper was laid over until next meeting for further discussion, and the Secretary instructed to send out copies to members and others who wished to discuss the subject.

Adjourned.] L. E. COOLEY, Secretary.

CIVIL ENGINEERS' SOCIETY OF ST. PAUL.

SEPTEMBER 3, 1888 :—Pursuant to adjournment at the June meeting the first regular meeting of the Autumn sessions was held Sept. 3, Vice-President Morrison in the chair ; 12 Members, one visitor present.

Routine of business having been disposed of the resignation of C. L. Annan as Treasurer was accepted, and F. W. McCoy elected to the vacancy.

The papers of the evening were : first, one by F. W. McCoy upon Street Improvements in St. Paul, giving a résumé of the amount, cost, and variety of different street improvements in St. Paul during the past two years ; second, Mr. J. D. Estabrook, Superintendent of Parks in St. Paul, followed with an interesting paper upon the Changes of Level in the Northwestern Lakes. Illustrated by maps and charts, giving the variations in the Great Lakes and others,together with comparisons with the rainfall for the last 25 years, a subject of special local importance in reference to Lake Como.

After discussion of the papers the meeting adjourned.

GEORGE L. WILSON, Secretary.

ENGINEERS' CLUB OF KANSAS CITY.

SEPTEMBER 3, 1888:—A regular meeting was held in Rooms 308 and 309, Baird Building, at 7:45 P. M. Mr. T. F. Wynne in the chair. Those present were Messrs. Wynne, Jenkins, Connett, F. W. Tuttle, F. B. Tuttle, Breithaupt, Bontecou, Florance, Taylor, Witmer, Hastings, Mason, Wells, Nier, Burton, K. Allen and nine visitors.

On a canvas of ballots—Messrs. Bontecou and Mason acting as tellers—Walton Clark and Edmund Saxton were elected Members.

After a description of a new cable railroad grip by Mr. Harris, the patentee, the Secretary read the minutes of the previous regular meeting. The Executive Committee had held three meetings, but had decided to defer engaging a new club-room until after the September meeting.

A communication from Mr. John F. Wallace was read entitled, "A Note on Flood Waves of the Missouri River," which was discussed by Mr. Nier.

A letter from Mr. B. W. De Courcy was read referring to Shrinkage in Embankments, and was discussed by Messrs. Burton, Nier, Bontecou and Mason.

The following were presented for the Club Library:

Proceedings American Society Civil Engineers, December, 1887, January and February, 1888; Proceedings National Association of Builders, 1888, with Standard Specifications for Architects; Proceedings Engineers' Club of Philadelphia, February, 1888, with Supplement; Proceedings Indiana Society Civil Engineers and Surveyors, 1888; Report Newton (Mass.) Water Board, 1888; Constitution and By-Laws Montana Society Civil Engineers.

[*Adjourned.*] KENNETH ALLEN, Secretary.

MONTANA SOCIETY OF CIVIL ENGINEERS.

AUGUST 18, 1888 :—The regular monthly meeting was held at the office of Mr. E. H. Beckler, Chief Engineer Montana Central Railway, at 7:30 P. M. In the absence of the President and Vice-Presidents, Mr. J. H. Farmer was elected Chairman.

The minutes of the previous meeting were read and approved.

The Secretary reported having mailed to each member of the Society on July 26 last, a circular relative to reform in highway bridges, as proposed in the report of the Committee on Highway Bridges of the Western Society of Engineers,

requesting the views of members upon the same; he submitted the replies received all being "Aye" to the three questions as put by said Committee.

Among the replies received was one from Col. J. T. Dodge, past President, in which he says :

"1st. In respect to the appointment of State Engineers.

"Were we to look for a precedent for the assumption of authority by the State to appoint an engineer whose approval must be obtained before any important highway bridge can be lawfully constructed, we should find that the State has taken supervision of many matters where private interests would otherwise be especially liable to suffer. It has appointed bank inspectors who are authorized to see that the business of banks is conducted in accordance with law. It appoints insurance commissioners to supervise and license insurance companies—without that supervision the insured would be entirely at the mercy of officers who held everything in their own hands. It only allows those to practice medicine who have received a commission from a legally established medical college. No lawyer can practice till he has been duly examined and admitted to the bar. Cities assume control of private building on the ground of public safety. They appoint building inspectors, to whom all plans of buildings must be submitted, and without his approval no work can be commenced. Cities also take charge of sewerage by means of an engineer. It is unnecessary to suggest to a society of engineers the absurdity of attempting that work by means of a boss mason and a gang of laborers.

"Now, there is no place where the public is more exposed to danger than in crossing a bridge ; there is no work where expert knowledge is more requisite, none where the average man is less qualified to judge of the merits of a piece of work. Every reason which justifies governmental control or regulation of any of the matters above stated applies with equal or greater force to the proposed supervision of highway bridges. * * *"

The subject was discussed at considerable length by the meeting, the tenor of all remarks being in full accord with those expressed by Colonel Dodge.

The question as to extending the duties of a State Engineer as proposed, to the inspection of railroad bridges, was discussed ; some holding that while with irresponsible or careless companies it might prove beneficial to the public, it would be a doubtful policy to inspect the bridges of a responsible company, for in case of the failure of a bridge of such a company, it might be legally held that as the State had passed the bridge through its official examiner, it should be held responsible. It was also suggested in this connection that responsible companies always secured at least as high talent at the head of their engineering departments as it could be expected the State would obtain, for the engineer, while in the service of the State would, to a large extent, be remunerated by the honor of the position, and the intense satisfaction afforded through the opportunity presented of serving the public, as is manifested in a large number of positions of public trust.

A vote being taken upon the three questions submitted by the Committee of the Western Society of Engineers, resulted in a unanimous "aye" to all. The appointment of a committee to co-operate with that Society was placed in the order of special business for the next meeting.

A circular was read from Mr. John Bogart, Secretary of Am. S. C. E., relative to the *Transactions* of that Society being open for the publication of professional papers to other than members of that Society; also that the *Transactions* were open to public subscription. The Secretary was authorized to subscribe for said *Transactions* in the name of the Society for the current year.

Mr. Geo. O. Foss read a communication to the Society reciting the difficulties encountered in endeavoring to define the locus of mineral locations from an examination of records in County Recorders' offices and suggested remedies. He recom-

mends the subject to the Society for discussion, and suggests that a memorial be prepared and submitted to the next Legislature praying for the enactment of laws looking to the overcoming of annoyances experienced, not alone in defining the locus and boundaries of locations, but also their ownership. The subject was discussed and the communication filed with the Secretary for reading and discussion at the next meeting.

After an hour spent in informal discussion of various engineering subjects, the meeting adjourned to meet at same time and place September, 15, 1888.

J. S. KEERL, Secretary.

ASSOCIATION OF ENGINEERING SOCIETIES.
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This Association, as a body, is not responsible for the subject matter of any Society, or for statements or opinions of any of its members.

THE TRANSMISSION OF POWER BY BELTING.

BY HORACE B. GALE, MEMBER ENGINEERS' CLUB, ST. LOUIS.
[Read March 7, 1888.]

Belts and pulleys have been for some thirty years our most common means of transmitting power. Hundreds of thousands of dollars are consumed annually by the wear and destruction of belts, while not infrequently as much power is wasted in transmission as remains to be usefully applied. A good deal has been written upon belt transmission that is now of extremely little value ; because, until within a very few years, no accurate knowledge of the subject has existed ; and as yet, so far as I am aware, but little has been done to systematize our lately acquired knowledge.

The rules in common use in machine shops and by belt manufacturers to determine the size of belt required to transmit a given power are mostly taken from handy books of reference, and differ enormously from each other. To illustrate this, I have calculated by several such rules the width of a leather dynamo belt $\frac{3}{16}$ of an inch thick, which is to transmit 60 horse-power to a 16 inch iron pulley making 900 revolutions per minute. According to Nystrom's Mechanics, this belt should be 10 inches wide ; Haswell's Engineer's Pocket-Book gives 17 inches ; while the rules published in the recent catalogues of two prominent belt manufacturing concerns would make it respectively 46 inches and 48 inches. Supposing the belt to be 50 feet long, the difference in cost between the 10 inch and the 48 inch belt would be, at present prices, something over one hundred and fifty dollars. In practice, a 16 inch single belt, or an 8 inch double belt, does this work well. Examples might easily be selected that would show a wider disagreement than exists in the case just cited. Many of the rules in use are little better than guesses; others are based upon experiment ; but even between these the differences amount in some cases to 100 per cent.

The chief aim of this paper is to bring together the most important results of some of the recent experiments upon belting, and to reduce them to such a form as may be readily and safely applied in practice.

The most important practical questions to be answered are:

First. What are the best materials, among those now in use, for belts, and for the pulley surfaces on which they run ?

Second. With given materials, what are the dimensions of belt and pulleys which will transmit the required power with greatest economy?

Third. Having determined upon the material and dimensions of the belt, how tight should it be stretched over the pulleys, and how are we to measure the tension put upon it?

Fourth. How do the different methods of joining the ends of the belt affect its efficiency, and what is the best way to make the joint?

The subjects of round belts, cords, link belts, and wire cables will not be included in this paper, which will be limited to the discussion of the transmission of power by flat belts of flexible material.

Of the materials in use for belts, the most common is leather; next follows rubber, (or, more exactly, cotton covered with vulcanized rubber); then comes cotton. This is generally in the form of a strong webbing or ducking, and is usually treated with a preserving coat to protect it from the action of the atmosphere and moisture. One type of cotton belt that does good service on harvesting machinery and in similar exposed situations, is made of several layers of strong duck, folded so as to bring the edges on the inside, and stitched together while under tension. The duck is soaked in oil and protected by what appears to be a thick, soft, red paint. The so-called "cotton-leather" belting is a comparatively new material. It is a woven cotton belt, with a thin facing of split leather glued upon one side to make a good surface to run upon the pulley. The number of stripes woven into it indicates the number of plies, or thicknesses, of the cotton, which is the strength-giving material of the belt. A good many belts of this kind are now in use, both for heavy and light service; and where protected from water, oil, etc., are doing excellent work. It is made by the Underwood Manufacturing Company, of Tolland, Conn.

For making rubber belting, a heavy duck of about 200 pounds tensile strength per inch of width is impregnated and coated on each side with a preparation of rubber, which is pressed against it between heavy rollers. Thus treated, the duck is cut into strips of the requisite width, folded, and pressed together by powerful heated rollers, making a belt of any required number of plies, three and four ply being the most common thicknesses. The long lengths of belting pass from the machine into the vulcanizing heater, where the process is completed. One firm of belt manufacturers still further unites the plies of the belt by longitudinal rows of cotton cord stays or flexible rivets, driven through the belt. These cords are cut to project about a quarter of an inch on each side of the belt, and are then imbedded in the rubber coating of the duck under pressure; the outer covering is then applied, and the whole vulcanized together. These belts, when well made, do very satisfactory work, and are especially adapted to use in damp places, or where they are exposed to the action of the weather.

Oak tanned leather, which was the material first placed on the market for this purpose, still holds its place at the head of belting materials. The hides of young steers are generally selected for belt leather, and only about 36 inches in width of the central portion of the hide should be used. After being soaked in lime water, unhaired and scraped, the extractive matter of the skin being dissolved out, leaving only the fibres

with some gelatinous matter, the hides are put to soak in a watery solution of tannic acid, where they should remain six or seven months. The duration of this process varies with different makers. A process lasting two years is said to make better leather, but the increased value is not generally thought sufficient to warrant the greater expense of manufacture. Various materials are sometimes used for making the tan liquor, but for belt leather, there is nothing known which answers so well as ground oak bark. After the tanning process, the hide is thoroughly washed by the currier, and after being allowed to get partially dry, is greased with tallow and cod oil, and hung up. As the moisture goes out, the oleine of the dressing penetrates the leather by capillary attraction, leaving most of the solid part, or stearine, to be scraped off from the outside. The oil which has penetrated the leather rapidly oxidizes, forming an elastic, gummy substance, which coats each fibre and binds them all together. The mechanical processes of currying and finishing also serve to compact the fibres, and the result is a great increase in strength and elacticity over the uncurried tanned leather. The leather thus prepared is cut into strips of the proper width for making belts, and "the stretch taken out of it" by suitable machines. Usually a single ply or thickness of leather is used for the narrow widths, two-ply for wider, and three or four for the very wide. These different thicknesses are scarf jointed at the ends, and put together with a cement made of a mixture of fish glue and ordinary glue under heavy pressure, breaking joint over the various unions when more than one thickness is used, so as to make a smooth, even band. Copper rivets, shoe pegs, stitching, and wire sewing or riveting are methods used to supplement the holding power of the glue, but these aids are unnecessary if the belts can be protected from water and machine oil when in use

The flesh side of leather possesses much greater tensile strength than the grain, or hair side, the part having the greatest strength being about one-third of the way through from the flesh side. On this account chiefly it is better to run the hair side of a single ply belt next to the pulley, placing the strength-giving part on the outside, where it is exposed to the greatest tension, and where it is also protected from wear. Double belts generally have the two flesh sides put together in the middle, and may run either side to the pulley.

The Shultz patent fulled leather differs from ordinary oak tanned leather chiefly in being left for a shorter time in the tan vats, so that it is fully tanned only on the surface, the inside being in a condition approaching that of rawhide. It is afterward subjected to a mechanical working over in a special machine, which makes it softer and more pliable than ordinary belt leather. Rawhide belting is even more pliable and elastic than Shultz leather. Rawhide is also an excellent material for belt lacings.

The cost of good leather or rawhide belting is at present from sixty cents to one dollar per square foot for single thickness, the wider belts being the more expensive. Three-ply rubber belting, which is about equivalent to leather of single thickness, costs about three-fourths as much per square foot. Cotton belting costs about half as much as leather.

Various other materials besides those mentioned have been and are occasionally used for belts, including among others gutta percha, wool, intestines, and paper. Even sheet iron has been successfully used for heavy work at slow speed.

Belts generally drive and are driven by friction, and their driving power, therefore, depends partly upon the *co-efficient of friction;* that is, upon the *ratio* which the *force required to slip the belt* over any part of the pulley circumference bears to the *normal pressure of the belt on the pulley* at the same point. The force which tends to slip the belt over the surface of the pulley, or the effective force exerted by the belt to turn the pulley, is the difference between the forward pull of the tight or driving side of the belt and the backward pull of the slack or following side. Now, assuming the co-effecient of friction to be uniform all around the arc of contact of the belt on the pulley, it can be proved that, where T_1 represents the tension on the tight side of the belt, and T_2 the smaller tension on the slack side, then the co-efficient of friction is given by the equation

$$f = \frac{0.37 \log. \frac{T_1}{T_2}}{A}$$

where A is the fraction of the pulley circumference inwrapped by the belt. The demonstration of this formula, or a formula equivalent to this, may be found in any book on applied mechanics, and as its mathematical accuracy is not questioned, I will not take the time here to demonstrate it. From this formula it is evident that if we can find the ratio of the two tensions required to slip the belt over the pulley at any desired speed, we can calculate the value of the co-efficient of friction corresponding to that speed of slip.

A great many experiments have been made to determine the value of f, especially for a leather belt running upon a turned cast iron pulley. Among the most noteworthy of the earlier experiments are those made by Gen. Morin, by Henry R. Towne, of the Yale & Towne Manufacturing Company, Stamford, Conn., by Edward Sawyer, of Charlestown, Mass., and by J. Howard Cromwell, of New York. All these gentlemen used the same general method, and seem to have performed their work with great care. A piece of belt was hung over a fixed iron pulley, or drum, and loaded at its ends with equal weights; then more weight was added on one side until the belt slipped. The ratio of the two weights was then taken as corresponding to the ratio $\frac{T_1}{T_2}$ in the formula for the co-efficient of friction. The different values of f obtained by these experimenters are here tabulated, the results being arranged in the order in which the experiments were made.

Experimenter.	Co-eff. of friction for leather belt on iron pulley.
Gen. Morin	f = 0.28
Henry R. Towne	f = 0.58
Edward Sawyer	f = 0.12 to 0.17
J. Howard Cromwell	f = 0.40

These results are sufficiently various to justify a belief that some important factor which effects the co-efficient of friction has been over-

looked. A little reasoning on the subject will suggest a possible cause for this variation. The theory of belts that has been generally accepted until recently, assumes that the co-efficient of friction of a belt on a pulley follows the same law as is approximately true for friction between metal surfaces, viz., that the co-efficient is independent of the pressure and of the velocity of sliding. Suppose that we have a motor driving a machine, for example a fan, by means of a belt, the pulleys being of equal size. If we apply a revolution-counter to each shaft, we generally find that the speed of the driven pulley is one or two per cent. less than the speed of the driver, showing that the belt slips to some extent on the surface of the pulleys. Now if we increase the speed of the motor under this condition of things, we shall increase also the speed of the fan ; but as the resistance to the motion of the fan is greater at higher speed, in order to accomplish this result the force applied to the pulley by the friction of the belt must increase also. It is also found that the belt slips more under the greater load than it did before. In other words, an increase of friction is accompanied by an increased speed of slip, which renders it probable that the ordinary laws of friction for metal surfaces do not apply to belts, and that the co-efficient of friction of a belt on a pulley increases with its speed of slip. Though these were matters of common experience, no one seems to have suspected their importance until a few years ago.

In 1882, Prof. S. W. Holman, of the Massachusetts Institute of Technology, undertook a set of experiments to determine how much the co-efficient of friction of a belt on a pulley is affected by the speed of slip, and whether the variation from that cause is sufficient to explain the enormous discrepancies in the results obtained by the earlier experimenters. The principal part of his apparatus was a pulley mounted so that it could be turned at various definite and rather slow speeds. Over this pulley was hung a piece of belt, a weight hung upon one end constituting the load on the tight side, while the load on the slack side was measured by a spring balance. The pulley being turned at a known speed in the direction tending to raise the weight, the effect is to reduce the tension on the spring balance below that corresponding to the weight by just the amount of the friction corresponding to the speed with which the surface of the pulley slides under the belt. By determining in this way the values of T_1 and T_2 at a series of different speeds, and substituting them in the formula already given, we can find the value of f corresponding to any desired speed of slip—the fraction of the circumference embraced by the belt, A, having the same value, one-half, in every case. Professor Holman wrote a brief paper describing his apparatus, and the results obtained with it, which may be found in the *Journal of the Franklin Institute* for September, 1885.

He found that with a speed of slip of 50 feet per minute the value of f was about 0.58, and with a very low speed of slip he obtained as small a value as 0.12, while for intermediate speeds he obtained values between these two.

These experiments finally settled the question of the variation of the co-efficient of friction with the speed of slip of the belt ; and as Prof,

Holman has pointed out, the introduction of this factor of speed of slip goes a good way towards accounting for the various results obtained by previous experimenters. Gen. Morin in his experiments loaded one side until the belt slipped, but does not tell us how fast it was slipping. Mr. Edward Sawyer, after loading the heavy side enough to make the belt slip, added weight on the light side until he just stopped the slipping, which accounts for his small value of the co-efficient (0.12), corresponding to the slowest speed of slip used in Prof. Holman's experiments. An account of his work may be found in the *Proceedings of the Society of Arts of the Mass. Institute of Technology* for 1881–2. Mr. Henry R. Towne, whose experiments are described in the *Journal of the Franklin Institute* for 1868, and who obtained the highest value for f, says that he allowed his belts to slip as near 200 *feet per minute* as he could judge by the eye. Mr. Cromwell, whose experiments are described in his recent book on belting, seems to have made no measurements upon speed of slip.

Evidently no theory of belting can be accepted which neglects this very important consideration of the speed of slip, and before we can make a rational formula for calculating the power which a belt can transmit, or the size of belt required to transmit a given power, we must first decide upon how much we are willing that the belt should slip on the pulley.

That we cannot transmit power in this way without *some slip*, may be proved by trial, or theoretically thus :

Let A and B (Fig. 1) represent a pair of pulleys connected by a belt. Suppose the pulleys are at rest, and the tensions on the two halves of the belt equal; then, in the case of a horizontal belt, the two sides sag equally, as represented by the lines c and f. Suppose we now mark a series of points along the edge of the belt exactly one foot apart. Now if the pulley A rotates and drives B, the tension on the lower, or driving, side of the belt will become greater than it was before, and that on the upper side will be less than before, so that the two sides of the belt will now be represented by the lines d and e. As a belt stretches under tension, and contracts when that tension is removed, the points on the tight side of the belt are now more than one foot apart, and those on the slack side are less than one foot apart. Now as the pulley B revolves, the number of points which pass on to the rim of the pulley in a given time must be just equal to the number which pass off it in the same time; that is, the number of divisions which pass the points h and k in the same time are equal; but as, on account of the difference in tension, the divisions passing k are each longer than the divisions passing h, the velocity with which the belt leaves the pulley at k is greater than the velocity with which it runs on at h; and the velocity of the belt increases constantly as it passes around the pulley B from h to k, the points in advance moving farther away from those in the rear, as the belt stretches under the increasing tension. In passing around the pulley A the reverse action takes place, the points in advance falling back so as to shorten the spaces, as the tension is reduced. As the velocity of the belt on each pulley varies at different parts of the circumference, while the velocity of the pulley itself is the same at all points of the surface, it follows that a belt made of any stretchable ma-

terial must always slip on the pulleys whenever the tension on the two sides is different; that is, whenever the belt is transmitting any power. This effect is called the *creep* of the belt. It always creeps backward on the driving pulley and forward on the driven pulley, so that the effect is to make the surface speed of the driven pulley fall behind that of the driver by a certain proportion, corresponding to the per cent. which the belt stretches in passing from the tension T_2 to the tension T_1. The loss due to this creeping effect, in the case of a leather belt under ordinary conditions, probably amounts to about $\frac{1}{2}$ of one per cent., or $\frac{1}{4}$ of one per cent. on each pulley, and cannot be reduced by tightening the belt. It can be reduced only by using a wider or thicker belt, or one that will stretch less under the required difference in tension. In addition to this effect there is frequently more or less true slip.

Some experiments have been made to determine what average speed of slip of belt on pulley is proper to allow. It has been determined that when the average speed of slip rises as high as 10 per cent. of the belt speed, the belt will generally fly off the pulley. Of course this limit should not usually be approached in practice, but a knowledge of it may be useful in determining the allowable fluctuations of speed in such tools

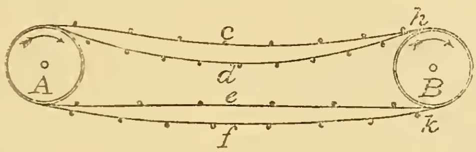


Figure 1.

as punching machines. Experiments made at the Massachusetts Institute of Technology in 1884 and 1885, under the direction of Prof. Lanza, indicate that the average speed of slip of a leather belt on an iron pulley should not exceed about $\frac{3}{10}$ of one per cent. of the belt speed. This would make the surface speed of the driven pulley fall behind that of the driver about $\frac{6}{10}$ of one per cent., which agrees with the practice in some first-class electric light stations and mills. In developing my formula for belts, I have therefore allowed a speed of slip of the belt on the pulley equal to $\frac{3}{10}$ of one per cent. of the belt speed. A larger allowance would simply change the constants of the equation, without altering its form, provided a *fixed proportion* is kept between slip and belt speed.

It is quite probable that the co efficient of friction of a belt on a pulley varies with the pressure, as well as with the speed of slip. From an elaborate series of experiments made by William Sellers & Co., of Philadelphia, and described in a paper by Mr. Wilfred Lewis in the *Transactions of the American Society of Mechanical Engineers* for 1886, Mr. Lewis thinks it probable that the co-efficient of friction generally increases as the pressure per square inch is reduced, a law which, if true, would be in favor of using arge pulleys. As this relation is not proved, and is, indeed, contradicted by the results of some other experiments, and as its effect is evidently not so important as that of the speed of slip, I have here made no attempt to take it into account. The co-efficient of friction of leather

belts on pulleys is also known to vary to a very great extent with the condition of the surfaces, the amount of belt dressing used, and somewhat with temperature and the condition of the atmosphere. These causes of variation, however, come under the head of accidental causes, which should nct properly be taken into account in a general formula for the width of a belt, which should make the width sufficient to do the work under the most unfavorable conditions liable to occur in ordinary practice.

There is need of further careful experiment to determine definitely if possible the relations of the co-efficient of friction both to speed of slip and to pressure. There is not yet enough knowledge of the subject to enable us to make an exact formula for calculating either the co-efficient of friction or the dimensions of a belt. What I have attempted to do, therefore, is to make as close an approximation to an exact formula as the condition of our knowledge will allow, and then to find the simplest expression which will represent it with sufficient accuracy for use.

I have first attempted, in the case of a leather belt on an iron pulley, (which is the only case for which there are sufficient experimental data), to establish some simple relation between the co-efficient of friction and the speed of slip. To do this I have collected the results of all the experiments I know of where the co-efficient of friction of a common leather belt on a smooth iron pulley, and also the corresponding speed of slip, have been measured, and have plotted them on paper, making abscissas represent speeds of slip and ordinates the corresponding values of the co-efficient of friction. Mr. Holman's experiments have been most useful, being directed especially to the determination of this point, and besides them I have included the results of some experiments by Henry R. Towne, by Professor Lanza, by William Sellers & Co., and of a few experiments made by last year's class in the Department of Dynamic Engineering at Washington University.

As might have been expected, considering the great variations that may be produced by what I have called accidental causes, the plotted points were so scattered that it was impossible to draw a curve that would even approximately represent them all; but it was found possible to draw a smooth curve bounding the lower side of the area occupied by the plotted points, and representing, therefore, the probable *minimum value* of the co-efficient of friction for each speed of slip. The experiments covered a range of speeds of slip from 2 inches to 200 feet per minute. Now, as a formula for calculating the width of a belt should make it sufficient to do its work well with the lowest valve which the co efficient of friction is liable to have under ordinary conditions, it appears that what is wanted for this purpose is the minimum, rather than the average, value of the co-efficient.

The curve thus obtained was convex on the upper side, rising almost vertically at first, and becoming nearly horizontal for speeds of slip above 50 feet per minute. Its equation, as determined by the well-known logarithmic method, is, approximately, $f = .207\ V'^{\frac{1}{4}}$, where f is the co-efficient of friction and V' is the velocity of sliding in feet per minute. That is to say, that as nearly as can be determined from experiments already made, it is safe to assume, for calculations within the limits of

ordinary practice, that the co-efficient of friction of a leather belt on an iron pulley varies approximately as the fourth root of the speed of slip; and that under ordinary conditions its value will not fall below that given by the formula just stated.

A good many experiments on the co-efficient of friction of belting have been made at a speed of slip of about 3 feet per minute; and it will be convenient to introduce into our expression for the co-efficient of friction a constant term corresponding to the value of the co-efficient at that speed. The mean value obtained by Prof. Holman at that speed, which result has been since confirmed by the experiments of Professor Lanza, was 0.27, which agrees very well with the value given by our formula. If we represent the co-efficient of friction at a speed of slip of 3 feet per minute by f', and by f the value of the co-efficient at a velocity of slip V', we may write

$$f = \frac{.207}{.27} f' \, V'^{\frac{1}{4}}.$$

(As $f' = .27$, the value of this expression is the same as that of the preceding one.)

Now as the co-efficient of friction varies with the speed of slip (which includes also the creep of the belt), and as the speed of creep, as well as the normal pressure, varies on different parts of the arc of the pulley embraced by the belt, it is evident that when a belt is running under the conditions of practice, the co-efficient of friction *will not be uniform* throughout the arc of contact, as is assumed in the derivation of the ordinary logarithmic formula; and moreover, it will vary in a different way on the driven pulley from what it does on the driving pulley; because in the one case the velocity of sliding, and with it the co-efficient of friction *increases* as we go from the slack to the tight side around the arc of contact, and in the other case it decreases. The effect of the creep in varying the velocity of sliding at different parts of the arc of contact of a leather belt on an iron pulley must be frequently sufficient to cause the co-efficient of friction to vary three or fourfold at different parts of the circumference. The smaller the per cent. of true slip of the belt the greater would be this variation. Evidently then, the formula

$$f = \frac{0.37 \log \frac{T_1}{T_2}}{A},$$

which can be derived only on the assumption of a uniform co-efficient, is not applicable to the general case of a belt transmitting power from one pulley to another.

However, neglecting the probably small variation in the co-efficient due to varying pressure, this formula is perfectly applicable to experiments like those of Mr. Holman; for where the belt stands still and the pulley turns under it, the velocity of sliding is the same at all points, and the value of f, as found in the ordinary way, is the true value of the co-efficient of friction corresponding to that speed of slip. This formula also gives the value of the co-efficient in experiments like those of Morin, —who, I believe, was the first to apply it,—that is, in cases where the belt is made to slide over a fixed drum.

Applying it, therefore, to such cases, we may place our two values of f equal to each other, and write

$$\frac{0.37 \log \frac{T_1}{T_2}}{A} = \frac{.207}{.27} f' \, V'^{\frac{1}{4}} \text{ or, } \log \frac{T_1}{T_2} = 2.08 \, A \, f' \, V'^{\frac{1}{4}} \qquad (1)$$

This formula, as we have seen, does not apply to the general case of a running belt; but for the special purpose of *calculating the proper width of a belt* to transmit a given power, the conditions are generally such that an equation of this form may still be used, as we will proceed to prove.

The necessary conditions are that the mean speed of slip V' shall bear a fixed ratio to the belt speed V, and the belt shall be strained to its maximum safe-working tension on the tight side. Under the latter condition. the true *creep* of the belt will also be nearly proportional to the belt speed; and with the usual arc of contact of about one-half the circumference, the variation in the velocity of slip at different parts of the arc of contact will follow approximately the same law at all speeds of belt. That is to say, that while the co-efficient of friction will vary at different points on the arc of contact of every pulley according to some function of the angular distance θ from the slack side, under the above conditions it will vary according to nearly the *same* function of θ at al speeds of belt. Also, for different belt speeds, the co-efficient of friction on each element of the arc of contact will vary proportionally to $V'^{\frac{1}{4}}$, where V' is the mean velocity of slip. Therefore the general value for the co-efficient of friction for any point of the arc of contact whose angular distance is θ from the slack end, and for any mean speed of slip V', may be written thus:

$$f = C \, V'^{\frac{1}{4}} \, F(\theta),$$

θ and V' being independent variables, and C a constant. Now let $d\,T$ be the difference in tension at the two ends of the elementary arc $d\,\theta$, and T the tension which draws the belt against the pulley at that point ; now it may be easily proved that the pressure on the elementary arc is equal to $T\,d\,\theta$; and the frictional force exerted by the belt on the elementary arc of the pulley is therefore $d\,T = f\,T\,d\,\theta$. Substituting for f its value, and transposing, we have $\frac{d\,T}{T} = C \, V'^{\frac{1}{4}} \, F(\theta) \, d\,\theta$, or

$$\int_{T_2}^{T_1} \frac{d\,T}{T} = C \, V'^{\frac{1}{4}} \int_0^{\theta} F(\theta) \, d\,\theta, \qquad (2)$$

$$\text{or } \log \frac{T_1}{T_2} = C \, V'^{\frac{1}{4}} \, F'(\theta) \qquad (3)$$

Now if the co-efficient of friction were *uniform* around the arc of contact, $F(\theta)$ in equation (2) would be unity, (or θ to the 0 power), and $F'(\theta)$, in equation (3) would therefore be simply the first power of θ ; but as f *increases* with θ on the driven pulley, for that case $F(\theta)$ would be some direct or positive function, and $F'(\theta)$ would be some function higher than the first power. On the other hand, for the driving pulley f *decreases* as θ increases, or $F(\theta)$ is an inverse function, making $F'(\theta)$ a function lower than the first power. However, as the arc of contact varies but slightly in ordinary practice, it will not be worth while to take this difference into

account and use separate formulas for driving and driven pulleys. The best way will be to take a function of θ intermediate between the two unknown functions applying respectively to driving and driven pulleys; that is, to use the first power of θ, which will make our equation read:

$$\log \frac{T_1}{T_2} = C \; V'^{\frac{1}{4}} \, \theta,$$

where T_1 and T_2 are the forces exerted respectively by the tight and slack sides of the belt to draw it against the pulley, θ is the arc of contact in angular measure, and V' is the mean velocity of slip allowed. As it is more convenient for general use to express the arc of contact as a fraction of the whole circumference, which we have before represented by A, we may substitute for θ in this expression its value in terms of A, changing the constant from C to C'. We have then

$$\log \frac{T_1}{T_2} = C' \; V'^{\frac{1}{4}} \; A,$$

an equation which becomes identical with equation (1) when we substitute $2.08 f'$ as the value of C'', which is thus determined. We then have, as an equation for use in determining the dimensions of a belt,

$$\log \frac{T_1}{T_2} = 2.08 \; A \; f' \; V'^{\frac{1}{4}}.$$

Now, as the velocity of slip V' should be a certain definite proportion, say $\frac{3}{10}$ of one per cent., of the belt speed V, we may still further transform this equation by substituting $.003\ V$ for V', which will reduce our constant to 0.5, making the equation read

$$\log \frac{T_1}{T_2} = 0.5 \; A \; f' \; V^{\frac{1}{4}},$$

where V is the belt speed in feet per minute. This means that for a fixed per cent. of slip the ratio of the two tensions $\frac{T_1}{T_2}$ would be the number corresponding to the logarithm $0.5\ A\ f'\ V^{\frac{1}{4}}$, which is expressed symbolically thus:

$$\frac{T_1}{T_2} = \log_{-1} 0.5 \, A \, f' \, V^{\frac{1}{4}}.$$

This equation may be transformed so as to read

$$T_1 = (T_1 - T\ ) \left\{ \frac{\log_{-1} \; 0.5 \, A \, f' \sqrt[4]{V}}{\log_{-1} \; 0.5 \, A \, f' \sqrt[4]{V} - 1} \right\} \qquad (4)$$

Now, T_1, or the force exerted on the pulley by the tight side of the belt, must not exceed a certain amount per inch of width, which the belt can safely withstand without excessive stretching. That is, if S' represents the available working tension of the belt in pounds per inch of width, and W is the width of the belt in inches, then

$$T_1 = WS'.$$

Now, when a belt passes around a pulley at high speed, a certain force is required to deviate the belt from a straight course, and make it move in an arc of a circle around the pulley, or, as commonly stated, a certain tension in the belt is needed to balance the centrifugal force; and this part of the tension is not available for producing adhesion to the pulley. Let w be the weight of a piece of belt one foot long and one inch wide,

and V as before the velocity of the belt; then the centrifugal tension per inch of width is equal to

$$\frac{87\,w\,V^2}{10^7}.$$

Therefore, if we substract this quantity from the working strength of the material per inch of width, we shall have left the working strength available for transmitting power; that is, if S represents the number of pounds tension per inch of width which the belt can safely and continuously withstand, then the available working tension,

$$S' = S - \frac{87\,w\,V^2}{10^7};$$

and, substituting this value in the last equation, we may put

$$T_1 = W\left(S - \frac{87\,w\,V^2}{10^7}\right).$$

Referring again to equation (4), the term $T_1 - T_2$ in the second member of the equation, or the difference between the forces exerted on the pulley by the two sides of the belt, represents the effective force transmitted, which is equal to the work done per minute in foot pounds divided by the distance traversed by the belt in feet in the same time. Or if $H\,P$ represent the number of horse power transmitted by the belt,

$$T_1 - T_2 = \frac{33{,}000\,H\,P}{V}.$$

Substituting, now, in equation (4) the values we have found for T_1 and $T_1 - T_2$, we obtain an equation from which we can find the proper width of belt to transmit any required horse power, without exceeding the assumed per cent. of slip, viz.:

$$W = \left\{ \frac{\left(\dfrac{33{,}000\,H\,P}{V}\right) \dfrac{\left(\log_{-1} 0.5\,A f' \sqrt[4]{V}\right)}{\left(\log_{-1} 0.5 A\, f' \sqrt[4]{V}\right) - 1}}{S - \dfrac{87\,w\,V^2}{10^7}} \right\} \qquad (5)$$

In this equation,

W = width of belt in inches; $H\,P$ = horse power transmitted;
V = speed of belt in feet per minute;
A = fraction of circumference inwrapped by belt;
f' = co-efficient of friction for a slip of 3 feet per minute;
S = safe working tension in pounds per inch of width;
w = weight in pounds of belt 1 foot long and 1 inch wide.

To apply this equation to other kinds of belt than leather and to other pulley surfaces than iron, we may substitute for w and S the proper values for the weight and safe working tension for the kind of belt in question, and for f' put the co-efficient of friction of the given surfaces at a speed of slip of 3 feet per minute; assuming, as our experiments so far indicate, that the law of variation of co-efficient of friction with speed of slip is approximately the same for each kind of belt.

I may here give the average weight of a foot of 1 inch belt $\frac{7}{32}$ inch thick for the various materials which I have tested. It will be seen that

the weights of the common materials do not differ very widely, rubber being the heaviest, and cotton the lightest.

	Lb.
Rubber	$w = 0.11$
Leather, best oak tanned	$w = 0.095$
Rawhide	$w = 0.091$
Shultz fulled leather	$w = 0.09$
Cotton leather	$w = 0.08$

These values are computed for a belt $\frac{7}{32}$ of an inch thick, which is about the ordinary thickness of a single leather belt. For other thicknesses the value should be proportionally greater or less. The *three-ply* rubber or cotton-leather belt corresponds in thickness to a single leather belt; that is, about $\frac{7}{32}$ inch. Rubber belts increase in thickness about $\frac{1}{16}$ of an inch for each ply, and the cotton-leather belts at the rate of about $\frac{3}{32}$ inch for two plies. Single Shultz belting is about $\frac{3}{16}$ inch thick, and rawhide about $\frac{5}{32}$ inch.

The safe working tension, or the greatest stress which a belt can continuously resist without undue stretching, depends upon the strength and elasticity of the material. In order to determine the relative strength of the different materials commonly used, a series of tests was made at the University last year by the students in dynamic engineering. The points investigated in these tests were the ultimate tensile or breaking strength, the elongation under a moderate fixed load, and the co-efficient of friction on a smooth cast-iron pulley. The tests were undertaken primarily to afford practice and instruction to the students, and make no pretensions to completeness, the number of specimens of each kind tested being too small to furnish close average values. The pieces used in the tests were all new, being supplied by the manufacturers for this purpose. The measurements of tensile strength and elongation were performed upon the Riehle testing machine in the laboratory of the University, the ordinary methods for tensile tests being used. A summary of the results is here given.

TENSILE STRENGTH AND EXTENSION OF VARIOUS KINDS OF BELTING. DEPARTMENT OF DYNAMIC ENGINEERING, WASHINGTON UNIVERSITY, ST. LOUIS, MAY, 1887.

Material.	Breaking stress in pounds per sq. in.			Extension at 400 pounds per sq. in.
	Minimum.	Maximum.	Average.	
Best oak leather	2,850	8,000	5,248	.018
Rawhide	3,000	6,754	4,889	.180
Shultz leather	2,990	5,666	4,618	.035
Rubber	2,913	3,888	3,360	.059
Cotton leather	2,969	3,714	3,465	.037

From the first two columns in the table it appears, as might be expected, that in each of the three forms of leather belt there is a wide variation in the strength of different specimens, while in the case of the rubber and cotton-leather belts there is much greater uniformity. The minimum figures for the five kinds of belting, however, do not differ

materially from each other. The relatively great extensibility of the rawhide belt is also noticeable. The extension tests, however, showed such great variations between different specimens of the same kind of belt, and the number of tests of each kind was so small, that these results cannot be considered as at all accurate measures of the relative extensibility. The time allowed for the stretch to take effect was merely that required to adjust the load and take the measurement, perhaps two or three minutes.

The inference drawn by the writer from these tests is that the tension that may safely be allowed in practice is about the same for all the above varieties of belting.

The percentage of the breaking load that a belt will bear and work satisfactorily can only be determined by experience in actual use. Most of the recent experimenters concur in recommending for a single leather belt a maximum tension on the tight side of about 66 pounds per inch in width, which would correspond to about 300 pounds per square inch, or one-tenth of the breaking load. The writer's experience with belts, both with those that have proved satisfactory and with some that have not, tends to sustain these figures. If it is admitted that the working strength per square inch of section is about the same for all the common kinds of belting, the selection of the best kind of belt to use in any case would therefore depend on other considerations, such as durability, cost, adhesion to pulley, and adaptability to the special conditions of the work. The belt of greatest driving power per inch of cross section would be that having the largest co-efficient of friction on the given pulley surface.

To determine the relative co-efficients of friction on cast iron at various speeds of slip, an apparatus on the principle of Prof. Holman's device was used, a small pulley being swung in a lathe so that it could be revolved at various speeds. The machine was rather crude, and no extreme degree of precision can be claimed for the results obtained with it. The strips of belt to be tested were hung over this pulley so as to embrace one-half its circumference, a weight hung upon one end constituting the load on the tight side, while the tension on the slack side was determined by a spring balance. The strips of belt used were each two inches wide and of a thickness corresponding to single leather belt, and were each subjected to exactly similar tests, the object being to determine the *relative* values of the co-efficient of friction for the different kinds, rather than to fix it absolutely for any one kind. With each piece of belt three different weights were used on the tight side, of 148, 104, and 51 pounds respectively, a set of observations being taken with each weight at various speeds of slip between one and sixty feet per minute. The pulley was rotated in the direction tending to raise the weight, the effect being to reduce the tension on the spring balance below that corresponding to the weight on the tight side, by just the amount of the friction. About thirty trials were made with each piece of belt at different speeds of slip, the latter being determined by counting the revolutions per minute of the pulley.

It was found that the force with which the belt is pressed against the pulley has a noticeable effect upon the co-efficient of friction, but the variation of the co-efficient with the pressure seemed to be irregular

and could not be reduced to any law, In every case the co-efficient of friction was found to increase rapidly with the speed of slip, the rate of increase being greater at low than at high speeds.

It is evident that in order to compare the co-efficients of friction of different kinds of belting we must place them under identical conditions as to pressure and speed of slip. In this case the comparisons were made at a speed of slip of three feet per minute, and with a load of 104 pounds on the tight side, these being selected as corresponding with the average conditions under which the belts would be used in practice. The relation between the average co-efficients for the different materials is shown by the following table, in which the co-efficient for oak tanned leather is called unity, no attempt being made to fix its absolute value.

Relative value of co-efficients of friction of various kinds of belting on iron pulley, as compared with leather.

Oak-tanned leather (hair side)	1 00
Cotton leather	1.15
Raw hide	1.17
Shultz fulled leather	1.30
Rubber	2.22

Taking 0.27 as the value of the co-efficient for leather on iron at a speed of slip of 3 feet per minute, this gives as the values of f' for the various kinds of belting the following :

Oak-tanned leather on iron, 3 feet per minute slip	$f' = 0.27$
Cotton leather on iron, 3 feet per minute slip	$f' = 0.31$
Raw hide on iron, 3 feet per minute slip	$f' = 0.32$
Shultz fulled leather on iron, 3 feet per minute slip	$f' = 0.35$
Rubber on iron, 3 feet per minute slip	$f' = 0.60$

These figures agree fairly well with the experiments that have been made at the Massachusetts Institute of Technology, except in the case of the rawhide belt, which their results would make about 0.41. The difference is, perhaps, due to a difference in the condition of the belt, that tested here being new and quite oily. We have as yet made no measurements of the co-efficient of friction upon lagged pulleys ; a few have been made, however, at the Massachusetts Institute of Technology, which, reduced to a speed of slip of 3 feet per minute, give for

Oak-tanned leather on a leather-lagged pulley	$f' = 0.5$
Rubber on a leather-lagged pulley	$f' = 0.7$

It is noticeable that the increase in the co-efficient for a lagged over an unlagged pulley is much greater for leather than for rubber, the co-efficient for leather being nearly doubled by lagging the pulley, while that of rubber is only slightly increased.

From the foregoing it would appear that, leaving out of account other considerations, (such as cost, durability, etc.), the best belt to run on a bare cast-iron pulley is a rubber belt. In case any other kind of belting is used, the pulley should be lagged, unless, for some special case, as a shifting belt, it is desirable not to have too great adhesion of the belt to the pulley.

The most complete of the modern experiments upon belting are those that have been made upon belts running under the conditions of practice. The first of this kind were made at the Massachusetts Institute of Technology under the direction of Professor Lanza in 1885, and a more extensive series was made at about the same time by William Sellers & Co.,

at Philadelphia. Both sets of experiments, with the results, are described in the *Transactions of the American Society of Mechanical Engineers* for 1886. The principle of the method used in each case was to suspend the driving shaft on a scale in such a way that the pull of the belt upon it could be weighed, giving the sum of the tension on the two sides, or $T_1 + T_2$; while a Prony brake on the driven shaft measured the force transmitted, giving the difference of the tensions on the tight and slack sides, or $T_1 - T_2$, from which two determinations the values of T_1 and T_2 can be easily calculated. A revolution counter was attached to each shaft, the difference in the numbers of revolutions in a given time determining the mean speed of slip.

These experiments have brought out a great many interesting facts, prominent among which is the fact that the sum of the two tensions, $T_1 + T_2$, does not remain constant under different loads, as has been assumed in the old theory of belting, (on the supposition that the stress is proportional to the strain), but that it increases with the load to the maximum extent of about 33 per cent. with vertical belts, its increase varying somewhat with the co-efficient of friction; and that in the case of a horizontal belt, where the tension on the slack side may be kept up by the weight of the belt, the sum of the tensions may increase indefinitely, as far as the breaking strength of the material. This fact should be considered in determining how tight a belt should be first stretched over the pulleys, in order to get the proper tension when running.

The formula for calculating the width of a belt which we have developed in equation (5) is evidently too complex for convenient use. I have therefore attempted by a graphical method to obtain a simpler equation, which would be at the same time sufficiently correct for use in practice. For this purpose I have constructed a curve representing the width of a single leather belt required to transmit 10 horse-power upon a cast-iron pulley at various speeds, when embracing one half the pulley circumference. In the diagram (Fig. 2) abscissas represent the various speeds of the belt in feet per minute, and the ordinates the corresponding belt widths.

The most noticeable thing about this curve is that the width of the belt at first rapidly diminishes as the speed is increased, then remains nearly constant for a certain range of speed, and as the speed is further increased the belt necessary to do the work becomes rapidly wider. This effect is due to the influence of the centrifugal force, which rapidly increases with the speed, until, at a speed of about 9,000 feet per minute, the entire assumed safe tension of the belt is needed to balance the centrifugal force, leaving nothing available for the transmission of power. At this speed the required width of the belt theoretically would be infinite. This curve enables us to determine a speed at which the width of belt required to transmit any given power would reach a minimum, which speed appears to be, for ordinary materials, between 5,000 and 6,000 feet, or about a mile a minute.

To determine the effect of varying the arc of contact of the belt on the pulley, I have plotted another curve, representing the width of belt required for the same work, when it embraces only three-tenths of the pulley circumference, the arc illustrated in the figure. The required in-

crease of width for this small arc, much smaller than is ever used in ordinary practice, is not so great as one might suppose who has never calculated it. In practice the arc embraced by the belt is very seldom as small as four-tenths of the circumference, and for any ordinary case a width intermediate between these two would suffice. It should be remembered that if the width is slightly different from the calculated amount, that the only effect will be to vary somewhat the per cent. of slip, so that considerable latitude is permissible.

To ascertain the effect of variations in the co-efficient of friction, I plotted another curve representing the belt width for the same work,

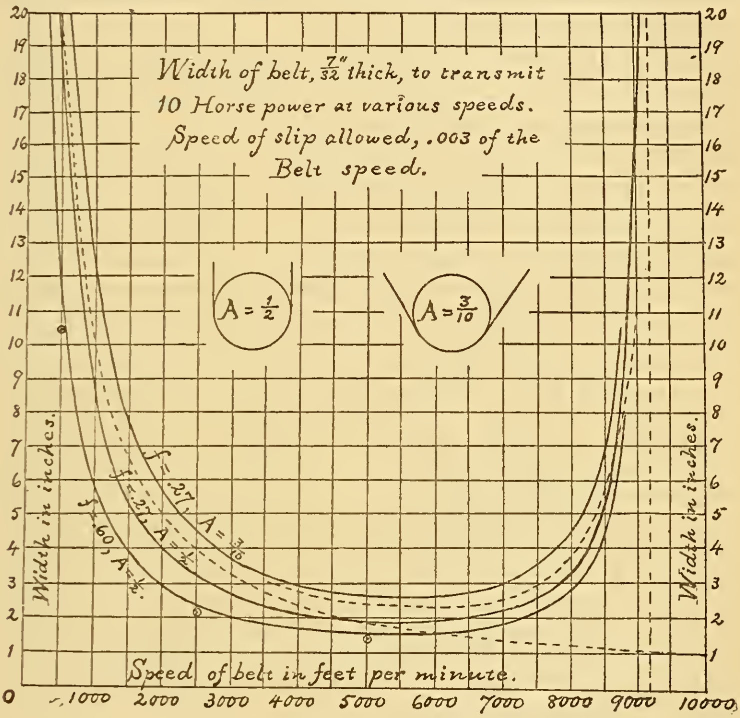


Figure 2.

and arc of ½ circumference, corresponding to a co-efficient of 0.6 at three feet per minute, the value given for a rubber belt. Evidently increasing the co-efficient of friction more than 100 per cent. does not reduce the width of the belt more than 25 per cent.; and when the coefficient is increased beyond 0.6, the effect in reducing the width of the belt is almost imperceptible. This is shown by the three plotted points, which represent the belt width for an arc of half circumference and a co-efficient of 1.4, which is the value indicated by some experiments for the co-efficient of a rawhide belt on a lagged pulley. This curve

indicates that in general the width of a rubber belt need be only about three-fourths as great as that of a leather belt, to transmit the same power with the same slip. As the wear on a rubber belt from slip is, however, more rapid than on a leather belt, some engineers make them of the same width, and run with less slip in the case of the rubber belt. The curve representing the width of the rubber belt also represents approximately the proper width for any of these belts on a lagged pulley. These results show also that whereas there is not much advantage in lagging a pulley in case a rubber belt is to be used, there is a great gain in doing so for a leather belt, as the belt in that case need be only three-fourths as wide, and will transmit the power with less tension, and consequently less journal friction.

In regard to formulas, it has been the writer's custom to calculate the width of belts by the handy rule that a one-inch single belt, traveling 1,000 feet per minute, will carry one horse-power; and that for other speeds, the width should be inversely as the speed. Expressed as an equation the rule would be $W' = \frac{1,000\ H\ P}{V}$, in which W' is the width of a belt $\frac{7}{32}$ of an inch thick. This rule has seemed to give uniformly good results under widely different conditions, in spite of the fact that it takes no account of the effect either of the centrifugal force or of the speed of slip. It occurred to me, however, that within the limits of practice, the errors made by neglecting these two factors tend to offset each other. Thus the tendency of centrifugal force is to diminish the driving power as speed increases, while the effect of the increasing coefficient of friction is to increase the driving power with higher speed. To determine how nearly these effect neutralize each other, I plotted another curve, using the simpler formula, and found that within the limits of ordinary practice the curve is very similar to the curves obtained from the theoretically more exact equation, and that indeed, the old simple formula is, within the limits of error of our existing knowledge, quite as correct as any formula that can be made. The curve, shown by the dotted line, follows about the line that the theoretical formula would give for an arc of $\frac{4}{10}$ of the circumference, except when we reach a high speed, like 5,000 feet per minute, when the effect of the centrifugal force begins to predominate, and the curve no longer corresponds to the correct one. These speeds are beyond ordinary practice; however, the formula may be made to apply fairly well to them by adding a correction, and making it read

$$W' = \frac{1,000\ H\ P}{V} + \frac{1,000,000\ H\ P}{(10,000 - V)^2}.$$

The effect of this correction on the curve is of no importance until we reach a high speed; then its effect is shown by the upper dotted curve.

One of the most potent causes of waste of power in large manufacturing establishments is the excessive journal friction in engines, shafting, and machinery, caused by the pull of heavy belts which are strained up too tight. When a belt is put on, the chief concern of the man who does the work is generally to get it on tight, so that it will not have to be soon taken up. He puts his screw clamps on it, and draws it up with

a tension limited more by his own muscular power and the leverage at his command than by the requirements of the power which the belt is to transmit. He is not apt to get it too loose, except, perhaps, in the case of an unusually large belt. For every case, however, we have a definite value for $T_1 - T_2$, or the effective force which the belt is to transmit, also a definite ratio between T_1 and T_2, depending upon the surfaces of contact and the belt speed; therefore there must be for every case a definite value for $T_1 + T_2$ (the sum of the two tensions), which, for a properly proportioned belt, may be calculated by the formulas we already have for the values of $T_1 - T_2$ and T_1. This means that in every case there is a certain definite tension with which the belt must be stretched over the pulleys, in order that it may not slip more than the prescribed amount. In calculating this initial tension, allowance must be made for the tension required to balance the centrifugal force, and also for the increase in the sum of the two tensions, when the belt is driving its load. It is evident that the proper initial tension would vary in different cases; but it is safe to say that the force with which the two ends of the belt are drawn together for joining should not generally exceed $\frac{3}{10}$ of the safe working tension, or, for a belt $\frac{7}{32}$ of an inch thick, 60 pounds to the inch n width. On the other hand, if the belt is put on too loose, it will slip excessively, causing harmful variations of speed, and wasting power in the same proportion as the slip, besides rapidly wearing out the belt. Not only this ; in a cotton mill, for example, a slip of 2 per cent. in the belts, where the power is transmitted through four or five of them before it is finally used, would cut down the entire product of the mill by from 12 to 17 per cent., the running expenses remaining the same as before. If the belts were, on the other hand, strained to unnecessary tightness, the effect would be immediately apparent in the increased power required, excessive heating and wear of journals, and larger coal, oil, and repair bills. It is oftentimes not a difficult matter to double the power expenses for a whole factory by simply varying the belt tension. These considerations should make us realize the great importance, whenever we transmit power through belts, of having them strained to just the right degree of tightness.

The proper way to put on a belt is to have the belt clamps provided with spring balances, and thus weigh the tension in putting on the belt. A belt clamp made in this way is a very cheap affair, and it is no more trouble to use it than it is to use the ordinary clamp. In any place where belts are used to transmit power to any extent, an apparatus of this kind intelligently used would pay for itself a hundred-fold in the course of a year.

The foregoing considerations also show us the wisdom of always using belts of ample width to transmit all the power required without undue stretching, and consequent change of tension ; and especially is this important where no ready means are provided for taking up the slack of the belt. It does no particular harm to have a belt unnecessarily wide ; but it always does harm to have it too narrow.

The great advantage of using adjustable straining pulleys is also apparent from the foregoing. The added resistance of such pulleys from

their journal friction should be almost inappreciable, and in the hands of an intelligent engineer or foreman they enable us to keep our belts always at the tension just required to drive without excessive slipping, and no more, in all conditions of the atmosphere, and without continually making a new joint in the belt to take up the slack. In the hands of an ignorant or careless man, however, who simply uses them to strain up the belts as tight as he can, they may prove an injury instead of a benefit. Where clutch pulleys, or tight and loose pulleys, are used, these straining pulleys, in common with such devices as sliding the base of a machine horizontally, or screwing it up and down, have the advantage of allowing us to relieve the strain on the belt and on the journals when the belt is not driving, and to put it on again when required. They also form one of the cheapest and best disconnecting arrangements for cutting off or putting on a part of the machinery while the engine is running.

From the curves of Fig. 2 it is evident that up to a speed of about a mile a minute the width of belt required to transmit any given horse-power becomes less and less as the belt speed is increased ; therefore, in order to get the cheapest belt that can be made to do the required work well, we should make our pulleys as large in diameter as possible, so as to run our belt at the highest attainable speed, within the limit of about a mile a minute, beyond which, the width, and therefore the first cost, of the belt would begin to increase.

The greater the diameter of the pulley, also, the less power is wasted in overcoming the stiffness of the belt in bending it around the pulley ; although the experiments of William Sellers & Co. indicate that the loss from this cause is generally an unimportant factor in the efficiency of transmission, the main sources of loss being *journal friction* and *slip*. Other things being the same, the loss from journal friction depends upon the force with which the shaft is drawn against the journals, which is directly proportional to the tension of the belt ; and as the necessary tension of the belt to transmit a given horse-power is inversely as the belt speed, it follows that the loss from journal friction is inversely as the belt speed. Hence, from all these considerations, the conclusion is, that to attain the greatest economy, we must increase our pulley diameter as much as possible, and run at a high belt speed. By decreasing the width of the belt and the breadth of face of the pulley, a high belt speed also tends to economize space, measured along the length of the shaft, which is sometimes an important consideration.

There are two considerations which fix a limit to the belt speed. One of these is the first cost, weight, and space occupied by the pulley, all of which increase with its diameter, although it should be remembered that at ordinary speeds the width of the pulley may be diminished as its diameter is increased. Except in extreme cases, the first cost of the pulley is relatively an insignificant item. If the pulley diameter is made excessive, however, we shall somewhere reach a point where its increasing weight will give rise to as much additional journal friction as is saved by the reduced belt tension. The question of space available to swing a pulley has, of course, to be decided from the circumstances in each case. The second consideration is that the width of belt and pulley have to be

rapidly increased if the belt speed is raised above say 7,000 feet per minute: and we may therefore fix that speed as about the limit beyond which an increase of pulley diameter and belt speed ceases to be profitable.

In case several machines or lines of shafting are to be driven from a single main shaft, a saving in space can be effected by arranging the various belts to *ride* one upon another on the driving pulley. Belts arranged in this way work about equally well as they do when run side by side. There is another case, however, where riding belts do not work as well; that is when a pair of belts, one riding the other, are used instead of a double belt to connect *one pair* of pulleys. In this case the inside belt does all the driving, the outer one serving merely by its tension to hold the inner one harder against the pulleys. If the belts are horizontal, the sag will appear as illustrated by Fig. 1, as the outer belt does not slip on the inner one, but maintains a practically equal tension on both sides. A pair of belts arranged this way will not always drive twice as much as one belt alone, and putting a third belt on top of the other two makes very little increase in the driving power. One belt of double or treble thickness is usually better than this arrangement.

In regard to joining the two ends of a belt, a glued lap joint is the best wherever it can be conveniently used. The ends of the belt should be scarfed off upon opposite sides for a distance back from the end of from eight to twenty inches, according to the width and thickness of the belt, and joined with a mixture of about equal parts of fish glue and common glue, applied hot, and kept under pressure for a few minutes. To complete the work, in the case of a leather belt, wooden shoe pegs may be driven through the joint, while in the case of a cotton belt, cross rows of stitching may be used. This joint is liable to be softened and give way if the belt is exposed to very much dampness. For such cases, a waterproof cement may be made by dissolving gutta percha in bisulphide of carbon to about the consistency of molasses. This is applied like the glue, the two ends of the belt, however, being warmed before the mixture is spread on. Molesworth gives the following recipe for a belting cement: 16 parts gutta percha; 4 parts india rubber; 2 parts pitch; 1 part shellac; 2 parts linseed oil. Cut the solid materials into small pieces, melt the whole, and mix well together.

In many cases, especially where a belt has to be frequently taken up, a laced joint is probably the most convenient. A belt is of course weaker at a laced joint than in the solid parts, but as it is ordinarily strained only to about one-tenth of its full breaking strength, its driving power is not thereby reduced. The safe working stress for a belt depends rather upon its *stretching* than upon its *breaking* limit, and a well-laced belt will drive about as much as a continuous one.

To make a good laced joint, cut the ends of the belt off square and punch holes exactly opposite each other in the two ends, putting two rows of holes in each end, arranged zig-zag. It is desirable, but not necessary, to have an odd number of holes in each end, the larger number being in the row next to the end. A 2-inch belt should have three holes, a 10-inch belt nine holes, in each end. The edges of the holes should not come nearer than seven-eighths of an inch to the end, or

nearer than three-quarters of an inch to the side of the belt, and the second row should be about an inch and three-quarters from the end. Begin to lace in the middle, working out at the same time to each side and back again to the middle, where the ends of the lacing may be tied together, taking care to have the knot on the side away from the pulley. In order that the belt may run straight it is important to lace each side equally tight. The lacings should not cross each other on the side next to the pulley, and it is better not to have them cross on either side. Where the strands of lacing do not run parallel to the belt it is important that there should be the same number of strands inclined one way as there are inclined the other way, otherwise there will be a tendency to slip one end of the belt to one side, so that the ends will no longer be exactly opposite each other. It is a good plan to arrange the strands next the two sides of the belt so as to run parallel with it. A method of lacing that fulfills these conditions, without crossing the strands on either side of the belt, is illustrated in Fig. 3.

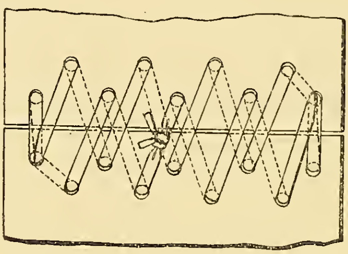


Figure 3.

Pulleys may be lagged either with leather or with paper. The leather should be put with the grain side out, stretched tightly round the pulley when moist, and fastened with copper rivets, holes being drilled in the pulley for that purpose. The paper used for lagging pulleys is usually a stout, coarse straw or wood pulp paper. To put on this covering, the surface of the pulley must first be thoroughly cleaned from grease and dirt by a solution of potash. The paper is covered with paste or a mixture of paste and glue, and wound on wet in several layers, generally not less than six, breaking joints around the pulley. When shrunk on in this way it becomes hard, and makes a firm, adhesive surface. I have seen layers of this covering wound on for an inch or more in thickness, in order to increase the diameter of the pulley.

Returning now to give definite answers to the questions asked at the beginning of this paper, in regard to the best materials for belts, I should say that for general purposes "there is nothing like leather;" but that it should always be run on a lagged pulley, unless there are special reasons to the contrary. In case the belt is to be exposed to water or dampness, and where lagged pulleys are not used, rubber belts will be found preferable. For very high speed, the cotton-leather, being

light and uniform in weight and texture, will be found to give good results.

With regard to the dimensions of the belt, I should use for a $\frac{7}{32}$-inch belt on an iron pulley, the formula

$$W = \frac{1,000\ H\ P}{V},$$

with the proper correction for speeds above a mile a minute. For lagged pulleys make the belt three-fourths as wide as for iron. Make the diameter of the pulley sufficient to give as near 7,000 feet per minute speed as can be done without making it too large and heavy. These considerations will of course frequently limit the speed to very much less than 7,000 feet.

Third, strain the belt to about 60 pounds to the inch in width, for a thickness of $\frac{7}{32}$-inch, using a tension-registering belt clamp.

Fourth, use a glued lap, or a laced joint, according to convenience.

HIGHWAY BRIDGES OF IRON AND STEEL.

By J. A. L. Waddell, Member of Engineers' Club of Kansas City—with Discussion.

[Read December 5 and 19, 1887, and Discussed April 2 and 16, 1888.]

ABSTRACT OF PAPER.

Note.—The original paper having already been printed in a pamphlet of 46 pages, and generally circulated, only an abstract is here given, but the discussion (which has not been published) is given in full.

Chapter I. is introductory. It makes the statement that there is urgent need for reform in the present methods of designing highway bridges, and that the iron highway bridges built to-day in the West are often more unsafe than those built five years ago.

The reasons given for this state of affairs, are first, indifference and a lack of knowledge on the part of the people, and, second, unscrupulousness and ignorance on the part of the majority of highway bridge builders.

It states that there are throughout this country a great many structures that are liable to tumble down, and indicates where a few of them are to be found.

Four methods of effecting the desired reform are suggested, viz., 1. State inspection. 2. An association of highway bridge builders who would be bound by a heavy penalty to build no bridge that would not have the strength indicated in certain standard specifications to be adopted by the association. 3. For county bridge supervisors to call for bids on the specifications contained in the pamphlet, and a specialist examine the designs submitted, award the contract and inspect the bridge after completion ; and 4, having complete detailed plans prepared by a competent specialist.

Chapter II. enumerates a number of highway bridge failures, many of which were accompanied by loss of human life, and quotes at length from a book by Prof. Geo. L. Vose, on "Bridge Disasters in America."

Chapter III. treats of bridge lettings, showing up the tricks of the

trade and how county commissioners are easily duped by the wily bridge-men. It touches also upon the other side of the question, and states that contractors have been forced to adopt the pooling system in order to protect themselves from loss caused by unfair dealing on the part of county commissioners.

Chapter IV. explains how bridges are built, and exposes the most glaring defects of design.

Among others are the following : Insufficient live loads, weak floor beams with stronger trusses, light joists, loose joints and connections, deficient portal bracing, the use of improper styles of truss for the purpose of saving a little metal, pony trusses without side bracing, long spans with narrow roadways, sections of main members so light as to permit of undue vibration, bottom chords unstiffened where buckling is liable to occur, neglecting the effects of induced stresses, the use of too thin iron, an insufficient number of rivets in the details and connections, the merest apologies for stay plates, rollers smaller than permissible, insufficient pin bearings, over-strained pins, badly stayed hand-railings, unstiffened webs in floor beams, absence of anchorage of trusses to piers and abutments, long rods not upset, inefficient extension plates on posts, inefficient chord splices, the use of rivets of too small diamete , rivet spacing longer than allowable, improper use of cast-iron, fish-bellied girders with web-section insufficient for the shear, and, worse than all these, rivets used in direct tension.

Chapter V. treats of how bridges ought to be built, going considerably into detail, but without the use of diagrams. The bridges here described are in conformity with the best modern practice.

Chapter VI. elaborates the idea advanced in Chapter I. concerning the formation of an association of highway bridge builders, explaining not only the benefits to be derived from such an organization, but also what steps it would be necessary to take in order to form the association. Although he treats this matter very carefully and concisely, it is evident from a remark made in Chapter I. that the author does not have much faith in the proposed method.

Chapter VII., which is the most important part of the pamphlet, occupying more than one-half its volume, presents a set of specifications that are intended to cover in detail the whole ground of highway bridge designing to such an extent that a dishonest designer would be unable to scamp the work to any appreciable amount without violating the requirements of the specifications. How well the author has succeeded is a matter of individual opinion ; but this much is acknowledged—that they are the most elaborate and complete set of highway bridge specifications that have yet appeared. Whether this completeness of detail is a good feature in specifications is a point upon which engineers disagree ; but considering the object which the author appears to continually bear in mind, viz., that he is writing for the purpose of effecting a much needed reform, this close attention to the designing of details is, to say the least, excusable.

Space will not permit the noticing of more than these few salient points of the specifications.

There are four classes of bridges specified, viz.: Classes A, B, C and D,

the first being for densely populated cities, the second for smaller cities and manufacturing districts, the third for country roads and the fourth for hilly districts where the loads are necessarily light, or for localities where the inhabitants are absolutely too poor to pay for heavier structures. The author discourages the building of bridges of the last class.

The floor live loads are the following: Classes A and B, 100 pounds per square foot; Class C, 80 pounds per square foot, and Class D, 65 pounds per square foot. The truss loads for short spans are the same as those for the floor, but for long spans the live loads reduce gradually, becoming 65 pounds for Class A, 55 pounds for Class B and 40 pounds for Class C, at spans of 350 feet, providing, however, that the truss loads per lineal foot are never less than the following:

Class A	1,800 lbs.	Class C	1,000 lbs.
" B	1,400 lbs.	" D	800 lbs.

For wide bridges there is permitted a reduction in live load per square foot of floor. In addition to the preceding there are specified local concentrated loads, affecting principally the joists.

The wind pressure specified varies from 30 pounds to 25 pounds per square foot of exposed surface, decreasing as the span increases, but for unusually exposed situations this is to be increased by 25 per cent. There are, however, minimum limits for the wind pressure per lineal foot of span, specified to prevent undue vibration.

Plate girders are recommended for spans up to 40 feet, triangular riveted girders from 40 to 65 feet, pony-truss pin-connected spans from 65 to 90 feet, and pin-connected through or deck-truss bridges with vertical intermediate posts and inclined end posts for longer spans.

Complete specifications are given for all portions of the floor system.

Considerable attention is paid to "limitations" of various kinds, the main object being to prevent the use of sizes so small as to reduce the rigidity of the structure.

The subject of rigidity throughout the specifications seems to hold a prominent place.

Symmetry in design, wherever practicable, is insisted upon.

The principal working stresses are thus specified.

Members.	Iron.		Steel.	
	Class A.	Class B, C and D.	Class A.	Class B and C.
Lower chord bars and end main diagonals (forged eye bars)	10,000	12,500	12,500	15,500
Lower chords (plates or shapes) net section	8,000	10,000	11,000	13,000
Middle panel diagonals and counters (adjustable members)	8,000	10,000	11,000	13,000
Middle panel diagonals (plates or shapes) net section	7,500	9,000	10,000	12,000
Hip verticals (forged eye bars)	8,000	10,000	11,000	13,000
Hip verticals (plates or shapes) net section	7,500	9,000	10,000	12,000
Beam hangers (loops)	7,000	8,000	.....	.....
Beam hangers (plates)	6,000	7,500	9,000	11,000
Lateral rods and vibration rods	15,000	15,000	.....	.....
Flanges of rolled beams	10,000	12,000	14,000	16,000
Flanges of built beams, net section	10,000	12,000	14,000	16,000

Working Tensile Stresses.—The intensities of working tensile stresses for iron and steel in the various members are to be as given in the preceding table, when the span does not exceed one hundred and fifty (150) feet.

The intensities for main diagonals between end diagonals and middle panel diagonals or counters are to be interpolated directly according to their position. If the span exceed 150 feet in length, the intensities of working stresses for chord bars and main diagonals are to be increased beyond those just given by 1 per cent. for each 10 feet of length beyond 150 feet, up to a limit of 400 feet, after which they shall remain constant and equal to those for a span of 400 feet.

The intensities of working stresses for other members than the chord bars and main diagonals are not to be increased with the length of span.

Angle irons subjected to direct tension or compression must be connected by both legs, or the section of one leg only will be considered as effective.

In members subject to tensile stress, full allowance shall be made for reduction of section by rivet holes, screw threads, etc.

Working Compressive Stresses.—For truss members of bridges of Class A the intensities of working compressive stresses in pounds are to be found by the following table :

Conditions.	Iron.	Steel.
Flat ends	$9{,}000 - 30\frac{l}{r}$	$12{,}000 - 45\frac{l}{r}$
One flat and one pin end	$9{,}000 - 35\frac{l}{r}$	$12{,}000 - 53\frac{l}{r}$
Pin ends	$9{,}000 - 40\frac{l}{r}$	$12{,}000 - 60\frac{l}{r}$

In which $\begin{cases} l = \text{length of member in inches from centre to centre of connections.} \\ r = \text{least radius of gyration of section of member, also in inches.} \end{cases}$

For truss members of bridges of Classes B, C and D, the intensities of working compressive stresses are to be found by adding twenty-five per cent. to the intensities given by the above table.

For members of the lateral systems and sway bracing of bridges of any class, the intensities of working compressive stresses are to be found by adding fifty per cent. to the intensities given in the above table.

Working and Bending, Bearing and Shearing Stresses.—The intensities of working shearing and bearing stresses on pins and rivets, and the working bending stresses on pins are to be taken from the following table :

Stress.	Iron.			Steel.		
	Trusses.		Lateral system and sway bracing.	Trusses.		Lateral system and sway bracing.
	Class A.	Classes B, C and D.		Class A.	Classes B, C and D.	
Shearing	7,500	9,000	11,000	9,000	11,000	13,000
Bearing	12,000	15,000	18,000	15,000	19,000	22,500
Bending	15,000	18,750	22,500	18,750	23,500	28,000

There are specified many other intensities of working stresses, referring principally to details.

The subject of riveting is thoroughly treated, rules being given that will cover all cases of ordinary practice.

In respect to quality of materials, workmanship, inspection and tests, the Manufacturers' Standard Specifications are adopted.

Chapter VIII. contains some remarks concerning the application of the specifications of the previous chapter, explaining the reasons for certain stipulations therein.

DISCUSSION.

By Samuel G. Artingstall.

I think there can be no difference of opinion as to the necessity for improvement, both in the way of awarding contracts for these works and in the design and construction, so as to secure at least a safe structure for the use of the public. The difficulty seems to me to be how this can be best accomplished. A combination of bridge builders does not appear to me as practicable, for the reason that there are too many who would try to take advantage of this combination by underbidding and building a structure which would not strictly be in accordance with the specifications, and I do not clearly see how this can be avoided unless the trustees employ a competent expert to advise, not only on the merits of the different designs submitted in competition, but also to see that the structure is built with members of suitable scantling, and that the workmanship is good throughout. In my opinion the way to get substantial highway bridges is for the legislatures of the several States to insist upon minimum strength in the several classes of bridges, and to appoint an expert engineer with such assistants as may be necessary, to whom all designs for highway bridges must be submitted and receive his approval before being built, and after erection to be examined and accepted before being allowed to be used for public use. If some such law could be faithfully executed in any State contractors will soon improve the character of their designs, and while competition would not be restricted, bridges would be safe and the public would soon gain confidence in their security.

By G. Bouscaren.

This movement against unscrupulous highway bridge builders is highly commended, but should be extended, I think, to the same class of dealers in railroad bridges.

I have very recently completed the inspection of some 600 miles of railroad, equipped with a variety of wooden and iron bridges, and with the fresh evidences of *sinful* designing collected thereby, I am more than ever impressed with the necessity of protective regulations broad enough to cover all classes of bridges. In fact, if any distinction were to be made in that respect as between highway and railroad bridges, it is quite clear to my mind that the latter's interest is by far the most important of the two.

First—Because the public has some means of redress against careless

or fraudulent awards of defective highway bridges, but it has none against railroad managers or construction companies.

Second—Because a highway bridge can be seen and criticised by any one passing over it, and attention may thus be called to glaring defects in its construction, while the true character of a railroad bridge must remain hidden to all but the inspector, if there be one.

Third—Because the number of people who risk their lives and limbs daily on dangerous railroad bridges is tenfold that who do the same on highway bridges.

The necessity for placing all classes of public work under the supervision of a competent expert who is not himself a contractor is universally admitted. Unfortunately there is no law making such employment mandatory, and if there was, it is likely that the same parties who award their work to the lowest bidder regardless of quality and quantity, would also select the cheapest "expert" regardless of quality.

A law regulating the construction of bridges should therefore provide general specifications for the same, and a competent expert should be appointed by the Governor of the State to inspect and verify the work done under these specifications.

The uniformity of specifications for all the States, although desirable, is not a matter of prime importance. I think that all engineers engaged in the independent practice of their profession agree now practically as to the main points, and the differences to be found in their specifications are but different modes of arriving at the same results.

But I consider it essential that the specifications, no matter by whom prepared, should be the work of an engineer entirely free of attachment with any manufacturing or contracting firm, otherwise the very object which they have in view would be defeated.

You will pardon me for saying that the manufacturers' and contractors' specifications, which you have made an adjunct to your own specifications, is the best example I can give of what I mean to convey.

As long as the object of the profession will be to do the most with the least money, and at the same time to place safety before cheapness, the engineer must aim to raise the quality of materials as well as the perfection of workmanship, because in doing this he eliminates many of the unknown elements which necessitate the so-called "factor of safety." Now, the manufacturers' and contractors' specifications do precisely the reverse of this.

By lowering the grades of materials and discouraging the thorough testing of the same, they introduce new elements of uncertainty, and make it necessary to *increase* the factor of safety, thus increasing the weight of material used and rendering their plea for economy an illusory one if the same measure of safety is to be retained.

These specifications were condemned by all independent engineers present at the convention where they were discussed, and the only reason which I can ascribe for the persistent effort made in favor of their adoption is to allow manufacturers who cannot produce the best grades of iron and steel to compete with those who can.

I hope that I may win you to my side in this question; but if I fail to do so, you will understand my reasons for not indorsing your circular.

I am ready and would be glad to join in any action tending to the effective protection of the public in the matter of bridges. So many of our most able men are personally interested in the question as contractors or manufacturers that unity of action in that direction cannot be accomplished without some sacrifice on their part, which, unfortunately, they do not appear, as yet, ready to make.

To the above, which was written as a letter to Mr. Waddell, I add nothing excepting to emphasize my objections to the "contractors' specifications," which are made a part of Mr. Waddell's. I should very much regret to see them endorsed generally, for the reasons given in my letter, and do not think that any unity of action tending to their support could be secured. I think it would be an easy matter for engineers to arrive at an understanding as to general specifications for highway and railroad bridges, which could serve as a standard for the regulation of that class of construction; but specifications, however carefully drawn, are of little value without proper supervision to interpret and enforce them. Hence the necessity of legislative action to give them force of law.

By W. H. Breithaupt.

Mr. Waddell's paper is most timely. Such a reform is particularly needed in the building of highway bridges in the West. Our immediate field of action is to agitate for an improvement in this State. By the laws of Missouri, county bridges are now let by public outcry to the lowest bidder. That this is not a good method of obtaining efficient work and of obtaining it at its true value has been sufficiently proved. Letting by tender is much the better way. Awarding of contract should be dependent on some one not in any way interested in any of the tenders; and to this there should be State officers as outlined in the pamphlet under discussion. The remedy there given appears to me to be much more feasible and leading to more reliable results than could be obtained by the proposed association of highway bridge builders. Right of inspection certainly belongs to the purchaser; and if he wants advice as to the article to be bought, he will go to some one independent of the seller. So in the case of the buying of bridges the purchaser would want to rely on the judgment of an outside engineer.

A scheme for State supervision might be generally outlined as follows: First, there should be a State engineer of bridges, or State bridge inspector, His holding of office, whether by appointment or election, and the former would seem much the better, should be dependent on his having had a certain number of years' experience in bridge work, and at least two years' experience in designing and in actual charge of work; and of his having successfully passed an examination, technical and practical, by competent engineering authority, State or national, the former for some reasons preferable.

The engineer should have the appointment of assistants, after they had passed a prescribed examination and otherwise proved their fitness. All bridges of any importance, say of span beyond a certain length, in public use, both highway and railroad, should then be subject to being passed on by the State engineer of bridges, either on his personal investigation or investigation by one of his assistant engineers. This qualifica-

tion as assistant State bridge inspector might be given to any engineer proving his fitness.

The author advises for spans of from 60 to 75 feet the use of pony trusses, which I take, from the previous sentence, to mean pin-connected trusses. In general it is inadvisable to use pin-connected trusses when overhead bracing is not available. Riveted trusses are stiffer, and better admit of proper fastening of batter bracing. When depth of floor—that is, distance from surface of floor to lowest part of bridge—is limited, the panel length often depends directly on this, shallow floor making short panels compulsory. But this is more often the case in railroad bridges.

The author gives the use of castings as a method of fastening lateral rods to floor beams. Use of castings in any part of the trusses or floor is inadvisable, from the fact that they are liable to break, unless made so heavy as to be bulky and uneconomical, as the author recognizes on page 38 in the specifications. I do, however, not agree with him in objecting to the use of castings in bolsters. The proper distribution of the weight on the stone is a subject generally not fully enough considered. A well designed cast bolster will do this more economically than an equally efficient wrought one, and will, from its bulk, be amply secure against breaking by vibration of the bridge. The classification of bridges for the various purposes as given is a very good one, and does not appear in any other specification I know of. It is difficult to see how wind pressure on anything but the moving load of the bridge can be a moving load.

For protection of guard rail on down grade the author specifies beveling of corner and use of flat plate. A square root angle to fit over corner of guard rail, as is largely used, is simpler of application and better when in place.

I see no use for reducing net section of bars in stiffened end panels 20 per cent. While punching holes in these bars would leave ragged edges and incipent cracks, drilling—as it is generally done or should always be done—in no way injures the material beyond what is actually cut away, in fact tests would tend to show that it is proportionally slightly stronger.

The author gives for requirements of steel, tension and pins, 60 to 68; compression members, 64 to 72; rolled bars, 58 to 66.

This is too slight a difference between tension and compression. Better have the two tension classes alike, say 58,000 to 68,000, and compression say from 70,000 to 80,000.

By W. H. Burr.

Probably no one will dispute the statement of Mr. Waddell which he has so forcibly supported, to the effect that much of the highway bridge business of the country is productive of most dangerous structures, which would not be tolerated under intelligent and honest supervision on the part of the proper county, town or city authorities ; but personal examination of a large amount of highway work during the past two or three years leads me to believe that at least some highway bridge builders are doing fairly good work, and are entitled to the confidence of the public. Such builders would doubtless be glad of any movement that

has for its objects the improvement of highway bridges and the extraction of good work from the unscrupulous builders or else their extinction.

So far as the flimsy and dangerous bridges are concerned, I believe it may be confidently stated that two causes render their existence possible; one is the combined ignorance and unscrupulousness of their builders, and the other, the ignorance and possible or probable corruption of a large number of the highway commissioners in many places, both evils being aggravated by the culpable apathy of the general public. The failures occurring every month demonstrate the existence of hundreds of miserable structures, and the widest possible publicity given them is the most potent factor in dissipating the indifference of the public. Interested engineers, as well as other interested and public spirited men, should have some concerted system by which every bridge failure would receive such attention that all essential details regarding previous condition and causes would be collected and permanently preserved, together with the name of the builder and date of erection or time of duration of the structure. The amount of loss of both money and life entailed by the wreck should also be ascertained. A careful and accurate account of the failure based upon the data thus obtained should then be written and given the widest publicity both in all the engineering papers of the country and the principal dailies. By such means the general public would be brought to realize not only the great losses caused by such inferior structures, but also the imminent danger in which a large portion of the community daily traverses the highway bridges of the country. The wide publication of the names of the builders of these tumble-down bridges would be an excellent advertisement of the dangerous character of their miserable wares, and would serve to notify the public that they and their business agents should be avoided. The constantly recurring notices of these disasters and their destructive consequences would stimulate in the public mind a growth of the right kind of interest in the matter of highway bridges, and would soon effectually dissipate the existing apathy and indifference. Such a constantly educating influence would soon induce or force the appointment of capable highway bridge commissioners with at least some integrity, who would not allow those builders to bid whose names become prominent through failures.

In this or some similar manner only, I believe, can public apathy be removed and a correct public sentiment be created. Unsupported by public sentiment, license, legal enactment or commissioners appointed by the American Society of Civil Engineers or any other body will be certain to result in vain efforts whose failures will leave the evils more firmly fixed than before. With it, however, the County Commissioners will need no extraneous impulse to seek tenders from either honest or honorable and competent builders, or the services of a consulting engineer who will furnish them such advice as will lead to the purchase of a substantial bridge.

The benefits of a pool are, to my mind, not by any means clear, although I do not doubt that which Mr. Waddell proposes, if conducted in the manner he indicates, would serve to remedy many existing evils.

Whether the organization could be kept in the original channels, seems to me, in the light of human experience, somewhat doubtful.

One thing is clear, however, in fact two things are clear, the present system of unlimited and indiscriminate invitations to tender for highway work breeds most pernicious evils and is most extravagant and expensive to counties, cities and towns. Such a comprehensive method induces bids from the good, bad and indifferent, with the first in a very small minority. Good designs are thus put alongside of the most wretched clap trap, which appears under a correspondingly low figure and is usually accepted. This is the first step toward a subsequent failure near at hand. Again, traveling and other expenses and "boodle" must, of course, be paid by the public who buy the bridges, and the greater the number of bidders, correspondingly greater must be the amount of expenses and "boodle." If the wise and discreet officers of town, city or county were to put their heads together to deliberately discover a method by which their constituents should pay the greatest possible price for the poorest and most dangerous bridge that would stand up in a presentable manner long enough for the builders to get their pay, they could scarcely succeed better than to advertise their bridge lettings in the local papers in the usual manner.

Invitations should be extended to a few responsible builders only, whose reputations and known competence and honesty would be a guarantee for satisfactory designs and substantial work as well as proper methods, whether bids are mailed or submitted in person. Highway commissioners utterly unfamiliar with the first principles of engineering and an easy prey to the devices of sharp and unscrupulous bidders can ill afford to have any conference with them, and should not venture to do so; but an open advertisement brings in a swarm of such parties and generally repels the best builders, since they know that honest structures cannot be furnished at the prices of their unscrupulous competitors. Whenever highway commissioners follow the example of the railroads, and invite a small number of bids from reputable parties, they will get good work and safe structures at economical prices, and not till then. Such conditions only will reduce expenses, and eliminate "boodle."

Little need be said regarding the specifications submitted by Mr. Waddell. They are admirable, and no exception can be taken to them. The most competent engineers may differ in opinion over points of detail, but such differences are quite unimportant and of no consequence.

By C. E. H. Campbell.

Professor Waddell very truly states that the average iron highway bridge as built in the West to-day is in many respects inferior to that built five years ago. As to the causes of this state of affairs, they are many and complicated. Eight years ago the average number of bidders found at a bridge letting was six, and every one of them was capable of designing and constructing a fairly decent structure: to-day the average number of bidders is fourteen, consisting of the following variety of talent: Seven representatives of companies owning shops, and competent to turn out good work; two contractors of reliability who do not operate shops; five incompetent hangers on who follow the legitimate con-

tractors from place to place for the purpose of getting money enough from them in the way of pools to live on without working for it, and who generally have more to say and more advice to give the officials who have the business in charge than the legitimate bidders have. This is the genius who is known by the honorable and appropriate title of Scalper.

This term should apply to any man who, after receiving a contract to construct a bridge upon a certain plan and specification, wilfully and purposely cuts down the sizes of materials in such a manner as to render the structure unsafe, and as has often been done, mutilates it to such an extent that some parts are only half as strong as others. This mutilation generally occurs in the rolled channel bars, lateral systems, floor beams and small details. The sizes of bar iron are seldom if ever changed, because even a County Commissioner can measure them and discover the shortage. The diagrams of stresses which are submitted by the majority of bidders and the sizes of materials specified are generally correct, but a comparison of this diagram with the structure as built is what will tell the tale. This is rarely, if ever, done.

It may be asked how are communities going to avoid the existing state of affairs. It seems to me that one of the easiest methods would be to refuse to entertain a bid from any person who is not prepared to demonstrate his ability (theoretically, practically and financially) to build the bridge desired. Then to control the proclivities of those who may be called competent builders would not be such a difficult matter. A community could either employ an expert engineer to make designs for their work to suit their requirements and means, then invite bids on said designs, and retain their engineer to see that the contract was carried out in every particular, or, if they accept the tender and designs of any bidder, require him to furnish copies of his working drawings to submit to the inspection of an expert, or if they cannot afford to do all this, let them accept what appears to them to be the best plan and specification and bid. from one of the bidders, then place the county seal on all papers, and not permit them to pass out of their hands or be changed, and when the bridge is complete to take these specifications and go over every part of the structure and measure the sizes, and if they find any variation from the specifications that upon investigation diminishes the capacity of the structure from that represented by the contractor, refuse to accept or pay for the bridge until the scant parts are made good. There is no honest or responsible contractor who will be afraid to accept these conditions, and any man who would not agree to the same should not be awarded a contract. The contractor should also be held accountable for any and all defects of construction that might be discovered even after the bridge had been accepted and paid for.

From the foregoing remarks it may appear that I have taken sides with the public against the highway bridge builders of the country. This is not my intention by any means. It may not be amiss to state that I have had an experience in building bridges in the West that covers a period of eighteen years, and have in that time come in contact with a great variety of public officials, and while I have many pleasant recollections of honorable and fair treatment from this class, I have also many of the opposite.

That close and niggardly dealing with contractors by the public occurs in many instances is a fact. That favoritism and prejudice have cheated many a contractor out of his just dues after being invited to bid on the work is another fact. That the unfair treatment of responsible contractors by public officials was the principal cause that produced the method of business known as pooling is another fact.

I believe it was my privilege to attend the first bridge lettings in the West where pools were formed, and the bidders present resorted to this method as a means of self-protection, for the reason that we could discover in a majority of cases a pre-disposition on the part of the officials of various counties to give their work to certain individuals, regardless of the claims or rights of the lowest responsible bidder. This would not have hurt so badly if they had sent for their favorite and given him their work to do, but they would send out invitations to every bidder in the country that they could hear of, and after the bidders had gone to considerable expense in preparing, perhaps, special designs for the work and traveling two or three hundred miles to the place where the contract was to be let, they would find upon investigation that a certain company had the "inside track" and would get the work if it were possible for the officials to give it to them. This was not a very pleasant matter to discover, and naturally led the contractors to devise some means of getting their expenses out of the community who had trifled with them. This method of doing business served its purpose as long as it was not abused, but in time it degenerated, and the fruit it bore was the "scalper," and the modern bridge-letting illustrates how the business has been carried on up to 1887. At the present time pooling is rather the exception than the rule.

The Professor proposes an association of highway bridge builders for the purpose of advancing the standard of work, and at the same time securing a fair remuneration for same. This is very desirable, but to form such an association is a difficult matter, owing to the jealousy existing between manufacturers, before mentioned. But should such a thing be attempted, it seems to me that the first order of business should be to compile and unanimously adopt a complete set of specifications that would cover every possible case in the highway bridge business. This being done it might not be possible to arrange the financial part of the matter, but if every company would agree to stand by the adopted specifications and put up a money forfeit as a guarantee of good faith; the bridges of the country would be well built, and contractors would certainly make as much money as they now do.

An association was formed a few years ago in which some twenty companies were interested; it was conducted in a first-class business-like manner, and was a financial success to all parties who stood by their obligations. The bridges were very fairly built. One of the largest companies in the country started to abuse its privileges, and get all the contracts, others followed and the association was dissolved at the expiration of the year, much to the regret of many companies who had endeavored to live up to their agreement.

I will not attempt to review or criticise the specifications in detail to any extent. That they are exhaustive, no one can deny. That they

treat of every necessary condition and case in the detailing of iron highway structures is apparent, as far as my knowledge goes. That they are rather voluminous may be an objection raised by some bridge designers, but I look at such matters in the light that when a man undertakes to write on such a subject he does not want to leave anything out. And designers who may make use of these specifications can allow themselves such latitude as their individuality suggests, without violating mechanical laws to any great extent, and their bridges will be practically perfect.

In conclusion, I may add that thus far I have had in view the well settled and comparatively independent parts of the Western country, whose people and traffic demand structures that are unquestionable in their capacity. But let us move farther west to the frontiers of civilization, if you please. Here we find new counties but lately organized. People are comparatively poor, but they have to travel, and the streams are in many cases just as important as in this part of the country. The people can ford these streams when the water is low, but do not want to run the risk of doing so when they have floods. They have a limited amount of money; they want a bridge. Materials are expensive on account of the distance from point of production. They call on an engineer to help them out by designing a bridge that can be built for the money they have. The engineer finds that he cannot do it and conform to standard specifications. What is he to do in such a case? It is quite a problem for him to solve, in which the element of chance plays the most important part; and the result to be determined is the difference between the chances of fording a dangerous stream or crossing a weak structure. I think that most of us would take the chances of crossing the weak structure, and would build it for them too. But in such cases the necessity of employing the skilled engineer who is master of his profession is apparent.

By W. L. Cowles.

I have read the specifications carefully, and am glad to say that, as a whole, they are calculated to insure work of the very best quality. They are very complete and cover all the details of design and construction fully. There are, however, a few points which, it appears to me, might be modified with profit, one of which is the specification at the foot of page 28, relating to the proportioning of sway bracing.

The intent of the method specified is evidently to equalize the stresses on the two trusses, as nearly as possible, by means of the sway bracing. At least this is involved in assuming that the trusses deflect equally. This appears to me to be unnecessary, as the heavily loaded trusses can never be thus loaded to its calculated capacity, and this condition is not likely to occur more frequently with one truss than with the other. Moreover, this method of proportioning would rarely give as heavy bracing as other considerations would call for. For example, it would require a load of 100 pounds per square foot on a 30-foot roadway, with a panel length of 20 feet and a depth of truss of 25 feet to call for a one inch round rod, which is as small as I think should be used in sway bracing, and a bridge of such or equivalent dimensions ought to have still

larger rods. If it is desired to carry the wind pressure on each panel to the bottom chord and thence to the end of the bridge, this would furnish a desirable specification. If not, it would be sufficient to specify the minimum size of rod to be used, and better than to use a principle which I conceive to be erroneous.

The specification near the top of page 31, concerning the connection of angle irons in direct stress, I cannot see the reason for, although I am aware that it is used in other specifications and by good authority. It is undoubtedly desirable to connect both legs when possible, but when it is impracticable, as, for example, in an end vertical in tension, composed of angles, I see no reason why the total net section should not be considered as effective, for the stress transmitted by the rivets is, it would seem, distributed through the entire section as effectively in an angle as in a bar. If it is argued that the stress applied to one leg cannot be effectively transmitted to the other leg "around a corner," then the same argument applies to the connection of angles in lattice girders mentioned on page 16—by auxiliary pieces of angle iron—a very nice connection for avoiding the use of a large gusset, but entirely unnecessary, as I consider, as a means of developing the full strength of the member, for if stress cannot be transmitted from one leg to another in a long angle it certainly cannot in a short one. This specification is harmless except in the matter of a lack of economy, but another specification strikes me as definitely detrimental to good results: I refer to that one near the foot of page 37, requiring uniform pitch of rivets in the compression flanges of stringers.

It is generally necessary to make the pitch very close at the ends where the actual stress is small but the increment large, and where the full section of the flange is not required. At the centre, where the stress is a maximum and the increment a mimimum, this close pitch is not required, and while it may be said in general that a rivet in compression is as good as the section cut out, still in a case like this it appears to me that the punching of holes as close as is required at the ends must break up the iron in a way that makes it less effective than it should be at a point where the entire section is required by the stress.

With the exception of these points the specifications seem to me to be peculiarly well adapted to their purpose, viz.: as a guide and a standard for those who are compelled to rely on the manufacturer through entire lack of knowledge on their own part as well as to those manufacturers themselves who are deficient in technical knowledge.

It is certainly very desirable that there should be a recognized standard, but still more necessary that there should be some authority to compel the use of the standard. It will be useless for engineers and bridge builders to agree upon a standard unless the buyers of bridges are obliged to purchase such only as conform to this standard. And this must be effected through the legislature directly, for the people are indifferent, trusting confidingly in those of their number who are selected to buy the bridges; and it is impossible to convince these latter that they can be deceived in the character of the structure procured—for is it not warranted?

But those having the power must be convinced of the necessity of appointing a state engineer, or of licensing a certain number of engineers,

from one of whom a certificate of the quality of every bridge must be obtained and deposited with the state.

The confidence of county commissioners in themselves is illustrated by an incident which recently came under my notice. A city having a number of large bridges to build let contracts for some of them, and afterwards discovered that they had paid much more than they ought in the shape of pool. The commissioners claimed that profiting by experience they could not again be taken in in this way, and proceeded to let some more contracts. The result was that they again furnished a large amount of pool, but I doubt whether they are aware of the fact to-day.

As is very ably shown in the preliminary chapters of the "Specifications," all this would be avoided, and much money be saved to the purchasers, if excessive pooling on inferior bridges were abolished, as it would be naturally if all bidding were upon standard specifications, and the plans were subject to the inspection of a state engineer.

By Palmer C. Ricketts.

Any one who has had experience as an engineer in highway bridge building must recognize the force of the statements made in that pamphlet as to the quality of the majority of them and the questionable methods often employed to secure contracts.

As to improvement in the quality of these bridges, the only method, in my opinion, is the employment of competent engineers to supervise their design and construction; but when it is remembered that the number of railroad companies in this country which have their bridges so supervised is in the minority, the average highway commissioner can hardly be expected to be more wise.

When the use of questionable methods to secure contracts is considered, the old saying that "It takes two to make a bargain" should be remembered, and the consideration of a general method for the improvement of the morals of highway commissioners in connection with those of highway bridge builders would be appropriate.

In the opinion of the writer competition will always prevent an efficient combination of any class of bridge builders, especially of highway bridge builders, as it has always prevented in the past efficient combinations of makers of unprotected articles which require for their manufacture comparatively inexpensive plants.

It is unnecessary to say that Mr. Waddell's specifications are first rate and that a bridge built under them would be a first class structure.

By C. L. Strobel.

I am heartily in sympathy with any effort to improve the present practice of highway bridge construction, but I attach little importance to general specifications for the accomplishment of this end, and I think an association of highway bridge builders on the plan and for the purpose outlined impracticable.

I hold that good results cannot be obtained by the system now in vogue, of receiving bids accompanied by designs under general specifications. Under this system the plans are competitive, and it is left to the engineer in charge to decide which is the best plan for the least money.

This is always a difficult task. He is expected to throw out inferior plans, even though they do not conflict with the specifications, if he finds that these plans do not furnish the most suitable bridge or the best in ultimate economy. Even if it were easy to decide this question, the duty is a most disagreeable one. It requires considerable force of character, and it subjects the engineer to the suspicion of favoritism. If he holds a position of public trust, he cannot well afford to incur this. Assuming, however, that he is competent and ready to make the proper decision, has he the power to carry it into effect? Often not. In most cases the contractor whose bid is the lowest will get the work, even if his design is faulty. In other words, contractors receive no encouragement to design work to the best of their ability. They very seldom get more than thanks for their trouble.

Another difficulty is this: General specifications permit of different interpretations. By adopting certain refinements of calculation, such, for instance, as the consideration of secondary stresses, a bridge can be made to cost much more than the contractor estimated. Under the usual form of contract the contractor depends upon the fairness of the engineer to a great extent as to what interpretation shall be placed upon the specifications. This is not business-like. To protect themselves in cases where engineers in charge are known to be unreasonable and one-sided, contractors are sometimes obliged to increase their prices to cover such contingencies, or they do not bid at all. If the engineer in charge is a bridge expert, and he ought to be, he will be competent to prepare his own specifications. He ought not only to do this; he ought also to prepare complete detail plans, and bids should be received on these. Cities and counties should be encouraged to engage bridge experts for this purpose. The question of compensation can be regulated in the same manner as done by architects. Rates should be established graded for different classes of work, and an understanding reached among engineers that charges shall not be less than these rates, though they may be more, subject to special agreement. The main reason why it is so difficult to get pay for engineering work is that there are no established rates.

Lastly, some pressure must be brought to bear upon county commissioners, and this can only be done by the appointment of State engineers, whose duty it shall be to examine and report upon bridges, to whom plans of public works shall be sent for record, and who will be expected to recommend to the legislature measures governing the construction of public works.

By Edwin Thacher.

Mr. Waddell's general specifications for highway bridges appear to be very complete, and if generally adopted would undoubtedlyresult in giving us much better and safer bridges, as a rule, than we now have. It will not be necessary to mention in detail the many good points in the specifications, as I suppose the Engineers' Club is more desirous of obtaining criticisms than commendations.

The greatest objection I have to the specifications is their great length, occupying twenty-four pages of closely printed matter, while it appears to me that all necessary directions could be easily condensed into one-

third of this space. Unless a specification is reasonably brief a busy calculator cannot take time to read it understandingly, and many provisions are liable to be overlooked. I would prefer to have general directions sufficient to insure a first-class bridge and leave most of the details to the designer.

I will notice a few points which I believe could be changed in the interest of simplicity without detriment to the specifications. The author uses live loads ranging from 40 to 100 pounds per square foot in multiples of five pounds, or thirteen varieties altogether. This is a matter of individual judgment at best, and it appears to me that four or five varieties would be sufficient.

Again, he makes the intensity of live load on sidewalks only four-fifths of the maximum on roadway. The heaviest uniform load that a bridge can be subjected to is a crowd of people, and if a bridge has sidewalks the crowd will take them in preference to the roadway. The rules given for the calculating of bridges with sidewalks are an approximation complicated and difficult to remember. They also err on the side of danger. With these rules omitted a correct calculation could be insisted on, and the calculation would, at the same time, be simplified. The weights assumed for timber appear to be rather light. The most thoroughly seasoned timber, only one inch in thickness, usually somewhat exceeds these weights. The small allowed variation between the actual and assumed dead load would too often result in recalculation. It should be sufficient to specify that the actual should not exceed the assumed load by more than, say, 3 per cent.

Under the head of "wind pressure" I think it would be sufficient to say that the lateral systems shall be proportioned for the following uniform rolling loads, viz.:

Unloaded chords, 125 pounds per lineal foot;

Loaded chords, 250 pounds per lineal foot,

adding two pounds per lineal foot for each foot exceeding 200 feet in the length of span.

It does not appear to me necessary to use a deflection formula for floor joists. Injurious vibrations are not caused by uniformly distributed loads, nor by wheel loads, but by the tramp of animals which bears no relation to the rolling loads assumed. The author appears to make no distinction in the strength of white and yellow pine, whereas the long leaf variety of the latter has about the strength of oak, except in resistance to shearing by sliding on the grain.

I think that the appearance of the bridge would be much improved by substituting for the hub planks or clumsy wooden hand railing specified by the author, a much lighter and neater hand railing protected by a guard rail of sufficient width to prevent the hubs from coming into contact with it.

The author gives preference to quadrangular forms of truss, but the writer much prefers triangular forms. Adjustable members are a bad feature in any bridge. They are liable to get out of order, and are subject to great abuse by unskilled inspectors.

I do not see any necessity of limiting the length of spans for double intersection trusses so long as the sizes of sections are limited, as mini-

mum sections can be used in single as well as double intersection trusses. The table, limiting the length of span for different distances between centres of trusses, does not appear to me consistent, giving about 11 diameters for 140-foot spans and about 23 diameters for 500-foot spans.

The top chords and end braces of a bridge may properly be considered as a long latticed column, whose length is the distance between end pins, and whose depth is the distance between trusses. This long column is subjected to the same stress per square inch as each individual panel length, and if it have a greater number of diameters, or more properly a greater radius of gyration than the panel lengths, the allowed stress per square inch should be correspondingly reduced, and as a maximum limit I would not allow the span to exceed twenty times the width between centres of trusses.

In finding the maximum effect of wind pressure on batter braces, bottom chords, trestle bents, etc., the author supposes the structure to be empty: such assumption gives only maximum counter stresses. The maximum stresses of the same kind as are produced by vertical loading occur under a full dead and rolling load.

I do not think it necessary to stiffen the end panels of the bottom chord, particularly in highway bridges. The chances are not one in ten thousand that they will ever be subjected to compression, and to stiffen them adds quite materially to the cost of the structure. Neither do I think it advisable to fasten the wooden joist rigidly to the floor beams, as the expansion and contraction of the iron due to stress or temperature will result in bending the floor beams, this effect increasing rapidly from the fixed to the roller end of span. If the ends of the bridge are properly anchored, due allowance being made for expansion, any possible reversal of stress in the bottom chords is resisted by the masonry, which is abundantly sufficient.

The specifications provide that the top chord and end brace sections shall consist of two channels with plate of uniform thickness above and lacing below. With such section it is not possible to place the pins in the same straight line and in the centre of gravity of the sections, and the use of the top plate at all for spans under say 125 feet in length, I consider the very worst feature of ordinary highway bridge construction. For such spans it is not practicable to place the pin much, if any, above the centre of the channels and leave room for the heads of the eye bars. In such unsymmetrical sections the eccentric stress is enormous, and when combined with the direct compression will ordinarily reduce the factor of safety fully fifty per cent.

Take for example an average case of two light 5-inch channels with a $12 \times \frac{1}{4}$ inch top plate—the safe strength per square inch of the combination is only about 47 per cent. of two channels of the same depth, laced on both sides. It is also much better to have every part receive its stress directly through the pins than indirectly through the rivets.

I would prefer to have only one class of bridges instead of four, the assumed uniform and concentrated rolling loads varying with locality, but everything else remaining the same, and I would consider a factor of safety of four with ordinary allowance for impact sufficient for any case. Railroad bridges are liable to get their maximum assumed load

every day, and several times a day, but a highway bridge in all probability will not get it once in ten years, if ever. This change would much simplify calculating and make an old estimate occasionally available. The specification assumes that no part of the web shall be considered as flange area, which is quite a common assumption. No rule, however, can prevent one-sixth of the web acting as flange area in each flange, or a portion of the web from taking the same stress as the angles between which it is riveted.

The author specifies that splice plates on plate girders shall have two rows of rivets on each side of joint, and that the thickness shall range from $\frac{1}{4}$ to $\frac{7}{16}$ inch.

Cases are rare even in railroad girders when $\frac{1}{4}$-inch plates with one row of rivets are not more than sufficient to take the shear.

The use of rods with bent eyes is forbidden, but in the writer's opinion such rods are sometimes very desirable, and far preferable in every way to nine-tenths of the substitutes for them. Tests on bent eyes made at the Keystone Bridge Works gave very satisfactory results. In submitting proposals the author calls for more work and expense than a bridge company can afford to be subjected to.

A sample strain sheet and specifications would be as satisfactory to an expert as anything further, and if not submitted to an expert, it matters little how much is shown. It should be sufficient if full detail drawings are submitted for approval before work is commenced.

So long as time lasts many good engineers will honestly differ regarding many points in a specification. Indeed, he would be a poor engineer who had no preferences. It appears to me hardly possible for all to agree on any one specification for highway bridges any more than has proved to be the case for railroad bridges.

Almost any of the specifications used by bridge companies are safe enough, and those are the best which give the greatest strength for the least money. The trouble is not so much in the specifications as in seeing that the specifications are faithfully carried out. This can be accomplished at a small expense by employing an expert of known ability to examine plans and strain sheets, and a competent inspector to examine sections, material and workmanship.

By A. J. Tullock.

I fully appreciate the difficulties we have to contend with in the present methods of letting contracts for public bridges. Owing to the fact that these lettings are in the hands of public officers, who are not familiar with the nature of the work to be done, nor able to discriminate as to the merits of proposals for doing it, I do not see any practical way of improving it, except by advocating the employment of proper consulting engineers, to take charge of such lettings.

If this can be accomplished, I would be very glad to co-operate with your Society, in any effort they see fit to make in that direction, and I think that most contractors, who have met with these difficulties, will gladly assist you.

By George L. Vose.

I hardly see how the proposed association is to be carried out. It is very easy to define what a good bridge is, and the good companies would be quite willing to agree to build nothing not up to the mark. Indeed, they have virtually done it already. But the trouble, it seems to me, will be to make the dishonest concerns that do so very large a part of this work, and who make their money by using an insufficient amount of poor material, agree to running the risk of losing their occupation. If the bad companies are forced to work up to good specifications their work will cost so much as to spoil their present profit, and they know it. If the bad companies cannot say to the town and county officers, "We will make you a *cheaper* bridge than the good companies will," their occupation will be gone. The bad companies care a good deal more about this kind of work than the good companies do, and I should think would be very apt to combine among themselves to keep it in their hands. I doubt very much if any organization can dictate to county commissioners what quality of bridges they shall build. The means used by the disreputable concerns to influence town and county officers are very potent. These officers, in most cases, don't want to be convinced, as far as I have known them. The fact that one concern offers to build their bridge *for less money* than another one is very apt to overbalance all other considerations. It is very hard to make a public officer understand that a factor of safety of two is not just as good as one of four. If one of these agents, with a good "gift of gab," tells them that the greatest possible load they can ever put on their bridge is not *a half* of what would break it down, they regard it as a wonderfully strong bridge, and as everything they need.

While I should welcome an association, or any other method for correcting the present evil, I hardly see how the plan of Professor Waddell is to effect the needed reform. There is, however, a power behind town and county officers, viz., public opinion; and, although the method is a slow one, I believe that a persistent endeavor to enlighten the public, and a timely sermon whenever a disaster furnishes a text, is about the only way to improve matters.

By De Volsen Wood.

Having had no experience in "bridge letting," I am not qualified to enter minutely into the details of the subject, and will only make one or two brief observations.

The evils of a community or of society are not removed by merely changing a system, and much less by shifting an organization. Any particular evil may be greatly modified and substantially removed by either of those methods, but new evils are liable to spring up which may be more burdensome and more difficult to remove than the former. Evils grow out of the selfishness of men, and the desire to make profits will be just as strong with an "association of bridge builders" as without, and if such an organization becomes successful it may be used to secure an unjus profit.

The evils complained of in Chap. III., bridge letting, exist, and their excessive abuse lies partly in the fact that the commissioners who are to

let the contract are ignorant of the "ways that are dark." I think that the evils complained of would be modified, if not entirely corrected, if commissioners were thoroughly acquainted with the fact that they are made to pay all those expenses in some way. For then some way would be devised by which they could be properly estimated and justly allowed I am aware that even in this case there would be difficulty in managing the matter, but the "inevitable" would compel some kind of an arrangement. Would not the evils complained of be avoided if the commissioners would "buy" their bridges, as a man buys what he wants by going into the market? In this case the commissioners would go to the builders and would see the necessity of being paid for time and expenses, and it would save certain expenses of the builders.

Again, let the commissioners employ an engineer to make a design and specification, and get estimates on those of such builders as they might select. (Would such an engineer be so selfish as to tax the builder a commission?)

It would not remove the evil by the commissioners agreeing to pay a certain amount for these expenses, for the "bidders" would probably treat this as so much clear profit, and make their "pool" as before. It would probably work like the "tipping" system in England. Formerly the servants in hotels, etc., depended upon gifts from patrons, but the patrons proposed to the proprietor to include the servants' fee in their bill and *give* nothing to the servants, and they do now include servants. attendance in their bill; but the custom of "tips" was so strong it was not banished, and now the traveler pays both the "bill" and "tips."

I trust that the agitation of this subject will result in a proper adjustment of these expenses, and so make them legitimate in *form* as well as in fact.

By Octave Chanute.

Of the number of remedies proposed for improvement in the present system of letting the construction of bridges, the one most advocated seems to be legislative action, and I will submit the following resolutions which have been suggested to me by this discussion.

Resolved, 1st. That a committee of three members be appointed by the President to prepare and submit to this Club a form of memorial to the Legislature of this State, together with the draft of a law inaugurating a proper inspection of bridges, and that for this purpose the Committee may consult with public spirited counsel, but without incurring expense except by special authority of the Executive Committee.

2d. That the Secretary be instructed to notify other engineering societies and clubs throughout this country of the action taken by this Club, and to solicit their co-operation in this movement.

3d. That in case of the appointment of similar committees by other societies, the Committee of this Club be instructed to confer and to co-operate with them in drafting the project for the proposed law, and in drawing up general specifications and rules to guide the State inspector.

Upon the main question and the statement of facts there is no divergence of opinion among those we have heard from. The ignorance of

the county commissioners is the main difficulty, and this we must accept as it is.

It is an irremediable trouble. They desire to save money, and fear public opinion, and the result is an unsafe structure. I believe there are within ten miles of this city a number of bridges which invite collapse.

The bridge builders would prefer to put up good bridges rather than poor ones, but their interest in the profits is such that there are many of them who will supply any demand, even if it be for a poor bridge. It follows, therefore, that any reform which is to be supported by the bridge companies must be compulsory on all of them. Of course, it is desirable that the county commissioners should employ experts to aid them in the inspection and selection of the plans submitted; but the effort to accomplish this has proved so futile that I believe it is useless. The adoption of any uniform specifications has also been impossible, although tried. In 1873, after a fatal bridge catastrophe in Illinois, the American Society of Civil Engineers appointed a committee to determine the best means of averting such disasters in the future. This committee was in existence four years and finally dissolved without reaching any conclusion, the various members having disagreed on numerous points. The public naturally concluded that if engineers could not describe accurately the difference between a good and a bad bridge, that there probably was not very much difference any way.

The objection to the appointment of a state officer to inspect bridges is, that such office may become a political engine, and perhaps even defeat the object for which it was created; but this I think can be avoided by the adoption of suitable means for the selection of this officer.

Another objection is, that the creation of the office might tend to divide the responsibility, which is now entirely with the bridge company. The endangering of life under the present system ought to have much more consideration than the fact that the responsibility for accidents might be divided under another system. Another objection which might be raised is the cost of supporting the office of State Bridge Inspector. I think that the office might be made self-supporting by having suitable fees allowed the officer for bridges inspected.

The discussion of the appointment of a State officer is in such shape now in various clubs that if the members of this Club take action so as to bring the matter before the Legislature of this State next winter they will not be alone; for similar action will be taken simultaneously in other States, and the public discussion thus provoked would undoubtedly aid in the passage of the various acts.

By J. A. L. Waddell.

When advocating a very general discussion of my specifications, I did so with the hope of discovering points to be modified, corrected or omitted in the second edition of the work, which edition will soon be issued. My desire has been gratified, and I think it will be found that the second edition will be an improvement upon the first. Of course it has been impossible for me to adopt the opinion of every engineer who has discussed the specifications, for no two engineers will agree exactly

upon everything, besides, if I tried to do so, the specifications would lose their individuality, and would of necessity conflict in different parts. Nevertheless, I have considered carefully each point that has been raised, adopting some suggestions, modifying and partially adopting others and rejecting the remainder.

Those adopted in part or in whole I will now discuss, and will give also my reasons for not accepting some of the others. Time and space, however, prevent me from discussing each and every consideration mentioned in the discussions.

In reference to vertical sway bracing I have concluded to change my method of design, leaving it to each designer to proportion the rods. The specifications will prevent their being made less than an inch in diameter. It is especially to bridges with sidewalks that my method of unequal loading would apply. Take for instance a bridge of 24 feet roadway and two 8 feet sidewalks, the panel length being 20 feet and the truss depth 32 feet, and assume that the top chord width is 1½ feet, also that the clear headway is 14 feet, which can be obtained by placing the overhead strut half way up the post. Take 100 pounds on roadway and 80 pounds on sidewalk. The transferred load in round numbers is 14,500 pounds, which multiplied by the secant (1.9 approximately) gives 27,550 pounds. Using an intensity of 15,000 pounds makes the section required 1.84 square inches, calling for at least a 1½-inch round rod, a size considerably greater than would be put in by guess work. If we were to proportion the rod to resist the transferred load due to a wind pressure of 150 pounds per lineal foot on the upper lateral system, the diameter required would be theoretically only about ⅝ inch, and it would make no difference whether there were sidewalks or not.

Moreover, it is not consistent to proportion these rods for load transferred by wind pressure, unless we make the lower lateral system strong enough to carry the total wind pressure above and below.

But as the structure would not be endangered were the rods under consideration entirely omitted (provided the portal bracing be properly designed), I shall, as before stated, omit from the specifications everything pertaining to this matter.

Angle irons should be connected by both legs, so as to avoid causing a bending moment on the piece. In order to develop the greatest strength, the riveting in one leg should extend well beyond that in the other. This is especially true for tension members of angle iron.

The reason why a uniform pitch of rivets is advisable for iron joists and short longitudinal plate girder spans is that it provides for heavy concentrated loads, in respect to both longitudinal and vertical shear.

In reply to some of Mr. Thacher's remarks I would state as follows :

1. That the specifications are made of unusual length for the reason that they are intended mainly as a safeguard against dishonesty and incompetency on the part of bidders. If commissioners were to state that they require bids upon these specifications and upon these only, and that they intend to submit all the designs to a competent engineer, highway bridge builders would soon become accustomed to designing bridges according to these specifications ; and as the latter are very complete in detail, the consulting engineer, with very little labor, by beginning with

the lowest bid and working upward, could readily determine which is the lowest bidder who complies with the specifications. Then, when working drawings are submitted, the engineer could hold the contractor strictly to specifications, for every detail is covered.

If for every bridge letting it were necessary to have an engineer prepare special specifications, a great deal of useless labor would be involved, and the majority of the specifications would be incomplete; for it costs money to get up specifications such as mine.

It is customary among bridge designers to make the sidewalk live load less than that for the main roadway, because of the less probability of the sidewalk receiving the maximum load of people. The truth is that such live loads as 80 and 100 pounds per square foot are nominal. They contain a percentage for impact and vibration. Actual loads rarely reach the lower of these figures. The element of impact or vibration should be greater for the main roadway than for the sidewalk on account of the greater frequency of the loading and its more active character.

My weights of timber per foot board measure might, perhaps, be increased advantageously by one-quarter of a pound each, although I think that the lumber when seasoned will not exceed in weight the figures that I have given.

I employ the deflection formula for joists as a check on the tendency to use small depths, as well as to prevent vibration. Moreover, the two formulæ in my specifications, when used together, will for all cases give just the size of joist which my judgment determines to be best. It might simplify matters to use tables of dimensions of joists to cover all cases.

The Pratt truss, in my opinion, is preferable to the Warren for two reasons. 1st. It is slightly more economical of material; and, 2d, it permits the riveting of floor beams to posts, which is decidedly preferable to suspending them as they are generally suspended. Beams suspended by non-adjustable hangers and securely stayed against all motion make undoubtedly good construction ; but it is expensive construction, and no better than that afforded by riveting beams to posts.

It may be well to use Mr. Thacher's $\frac{1}{20}$th as a limiting ratio of width to the length of span, but it would not be well to employ it as a constant. For instance a 400-foot span 20 feet wide would be all right, while a 200-foot span 10 feet wide would not. The reason for this is that the longer the span the less the probability of its ever receiving the maximum wind pressure over its whole area.

I still adhere to my method of proportioning bottom chords to resist the compression due to wind pressure, where such occurs. What is the use in proportioning the lower lateral rods for a wind load, which, if applied, would buckle the windward bottom chord and destroy the structure?

I agree with Mr. Thacher concerning the necessity for balanced sections and shall modify my specifications accordingly.

As for relying upon the webs of beams to resist bending, I have at times used both methods. That of counting in the web is more exact, but that of rejecting it is more convenient. By adjusting the intensities of working stresses the two formulæ may be made to give practically equal flange areas for all ordinary beams.

Although we may state that it is the function of the web to resist shear, still it does aid in resisting bending, hence my reason for specifying sizes of web splice plates which Mr. Thacher considers excessive.

In answer to Mr. Breithaupt I would say that my reasons for reducing intensities of working tensile stresses in stiffened end panels of bottom chords are:

1st. The rivet holes in the eye-bars are very liable to be punched, even if drilling be specified.

2d. That riveting on the stiffening induces initial stresses in the member. And

3d. In order that I may be to a certain extent in accordance with the gentlemen who are advocating the use of the Launhardt-Weyrauch formula, which, by the way, I see no necessity for using unless the reversion of stress be rapid and of frequent occurrence.

The *Indian Engineer* objects to my using a pressure of 300 pounds per square inch on masonry, and rightly so for some masonry.

In the second edition I shall use a sliding scale of pressures varying from 130 pounds for brickwork up to 500 pounds for granite of best quality.

There are other points in my specifications criticised besides those above mentioned, but the differences involved are simply those of opinion.

It is very gratifying, indeed, to me to have the matter of reform in highway bridge building taken up in such a thorough and earnest manner by the Engineers' Club of Kansas City, and to see that the move which they are making is being followed by many of the local engineering societies throughout the country.

Concerted action on the part of these societies, tending towards legislative action, ought eventually, if continued long enough, to accomplish the much needed reform to which my efforts have for many years been devoted.

CHARLES LATIMER AND W. L. BAKER.

MEMOIRS BY JOHN W. WESTON AND G. A. M. LILJENCRANTZ, COMMITTEE OF THE WESTERN SOCIETY OF ENGINEERS.

[Read September 5, 1888.]

It is with sincere regret that your committee finds itself called upon to place on record memoirs of departed members, and the following meagre tributes to two men, from whose separate lives and characters we believe we may each gather lessons, which assimilated, will help us, are respectfully presented that all our members may join us in our sorrow.

CHARLES LATIMER, OF CLEVELAND, OHIO. DIED MARCH 25, 1888.

* * * * * * * * * *

Charles Latimer was born in Washington, D. C., Sept. 7, 1827, and died in Cleveland, Ohio, in his sixty-first year, March 25, 1888. He traced his descent from the English martyr, Bishop Hugh Latimer, after whom his son was named.

Mr. Latimer was appointed a cadet in the U. S. Naval Academy at

Annapolis at the age of fourteen, graduated from there with credit and remained in the government naval service in all about thirteen years, one year of which as assistant professor at the Naval Academy and the remainder chiefly in sea service.

When the war broke out, Mr. Latimer promptly and unhesitatingly joined the Union forces, although of Southern parentage and residence, and served the government with zeal and enthusiasm, most prominently as an assistant engineer in the U. S. military railway service. His military activity ended in 1864–5. During this period, in connection with his previous experience as a naval officer, the foundation was undoubtedly laid for Mr. Latimer's most remarkable trait, his notable executive ability in the selection and management of men.

At different periods Mr. Latimer devoted himself to steamboat service, but it was in connection with railroad work, for many years, that his name became so well and favorably known, both inside and out of the engineering profession. His career in this branch commenced in 1854, when he was 27 years old. He was at different times connected with several different railroad corporations, and with either of these, and in all instances, his services were appreciated and recognized, as indicated by never-failing rapid promotions.

The corporation with which Mr. Latimer was most prominently identified, and for by far the longest space of time, was the New York, Pennsylvania & Ohio Railroad. By successive stages he reached the position of Chief Engineer for that road, in 1874, and which he held constantly until March, 1886, when the consolidation of the road with the Erie, and a consequent change of management, caused him to resign.

He was then offered the position of Consulting Engineer, or Engineer for the lessor company, which he accepted and held to the day of his death.

The so well known and extremely valuable invention, the "Latimer Rerailing Guard," was the product of Mr. Latimer's brain. It was made in 1871, and is almost universally approved and very extensively used.

Mr. Latimer was very widely known to persons of almost all classes and conditions by his enthusiastic belief and interest in what he called the "divining rod," and in the construction of the pyramids by divine inspiration, basing upon the latter theory the firm conviction that an abandonment of the English weights and measures, clearly defined in the pyramids, as he claimed, would be positively sacrilegious. Those who cannot join in these views (and beliefs) must, nevertheless, confess to a feeling of admiration and respect for the genuine sincerity and ardent zeal wherewith he advocated these his pet tenets, and may we not willingly agree that what we cannot disprove we should not contradict?

Mr. Latimer was recognized as being truly and sincerely religious, not merely in the attendance of the regular service in the church but in the daily walks of life and in his dealings with his fellow men, and he was in consequence loved and respected by all who knew him.

Mr. Latimer was a member of the American Society of Civil Engineers and of the Civil Engineers' Club of Cleveland, as well as of our society, of which he became a member February 10, 1873. Being a non-resident of this city, he was but seldom seen at our meetings, and was

not, on that account, as well known *personally* to the members of this society as he was *professionally* known to the engineering profession at large.

Mr. Latimer was married, in 1866, to a Miss Lombard, of this State, who made him a devoted and loving wife, and by whom he had four children, three daughters and one son, who survive him. Mrs. Latimer died in 1875.

The following eloquent tribute to Mr. W. L. Baker, of Detroit, Mich., has been written by one of intimate association :

W. L. BAKER, OF DETROIT, MICH. DIED MAY 28, 1888.

William L. Baker was born at Toledo, O., June 16, 1850. He was the eldest son of William Baker, the well-known lawyer of that city. He early developed a liking for mechanical and mathematical studies, and his education was naturally turned in that direction. He passed through the Polytechnic Institute at Troy, N. Y., being graduated in 1871. He immediately engaged in active professional duty, serving as Assistant Engineer in the construction of the bridge then being built across the Mississippi River at Hannibal, Mo., and subsequently of the bridge over the Missouri River at St. Joseph, Mo. The interest that he took in these enterprises and the capacity that he exhibited showed that his natural tendency was toward bridge engineering, and in 1872 he took service with the Detroit Bridge and Iron Works, of Detroit, Mich. Here he found congenial duty, and his life work was done. Commencing in a subordinate position, he developed such fidelity and capacity that promotion naturally followed, and he was advanced from rank to rank until he finally became Engineer and Superintendent of the entire establishment. He loved his work, and always found in it his chief pleasure, for there was room and opportunity therein for the development of his best faculties. The establishment with which he was connected has been for the last twenty-five years largely engaged in engineering construction, and to Mr. Baker is due much of the credit for its success. No one can ride over the great railways of the Northwest without passing over many iron bridges which were designed and built under his supervision. They bear silent witness to his professional capacity and honesty.

In addition to being an excellent technical engineer, he was also a good executive officer and manager. He was a man of affairs, a good judge of men, was keen-sighted and quick-witted, and capable of recognizing and appreciating merit in his subordinates. He instinctively gained the respect and liking of his men, and they were naturally true and loyal to him. He was honest in his work, and while he always sought economy he never allowed scamping. He insisted on thoroughness and fidelity in the execution of contracts, and no one ever knew him to wink at or permit slackness or inferiority of work.

Added to this high professional character he was by nature a genial, kindly gentleman. Of winning manners and pleasant address, every one that knew him liked him. Hosts of friends all over the country mourn his untimely taking off.

About two years ago his health began to fail. His characteristic pluck

and energy showed itself in the way he fought growing weakness and distress. Last fall he went abroad for a few months, hoping relief by rest and recreation. But it was in vain, and he returned no better than he went. His physical ailings finally terminated in consumption of the lungs, and the end came May 28, 1888. He died peacefully at his home in Detroit, surrounded by his family and friends, and when he quietly sank into the great final rest many fond loving hearts were sorely stricken.

He became a member of our Society of Civil Engineers, November 10, 1873. Although his residence at Detroit was so far from the headquarters at Chicago that he could not often attend our meetings, yet he was known to most of the members. And we as individuals as well as a society feel that in his death we have sustained a great loss.

He was married in 1879 to Miss Kate Mead, of Lockport, N. Y., who, with two children, survive him.

He died at the early age of 38 years. His career, which ought to have been just opening, was untimely shortened. Life was fair and bright and hopeful before him—but the end came. We can only bow our heads in humble silence under such mysterious Providence.

ASSOCIATION OF ENGINEERING SOCIETIES.

PROCEEDINGS.

BOSTON SOCIETY OF CIVIL ENGINEERS.

OCTOBER 17, 1888 :—A regular meeting was held at the Society's rooms, Boston & Albany Railroad Station, Boston, at 19:30 o'clock, President FitzGerald in the chair, thirty-nine Members and ten visitors present.

The record of the last meeting was read and approved.

Messrs. Edgar P. Sellew and Charles W. S. Seymour were elected Members of the Society.

The following were proposed for membership :

Frank A. McInnes, of Dorchester, Mass., recommended by Sidney Smith and M. T. Cook; J. Parker Snow, of Somerville, Mass., recommended by S. E. Tinkham and J. E. Cheney; and J. Frank Williams, of Lynn, Mass., recommended by M. M. Tidd and W. A. Favor.

On motion of Mr. Hammatt, it was voted, That the thanks of the Society be extended to Mr. J. Pickering Putnam, for the very interesting paper read at the last meeting.

On motion of Mr. Howe, the Secretary was requested to acknowledge in the name of the Society, its appreciation of the attention received from Mr. George H. Norman on the occasion of the excursion to Newport, also its appreciation of the courtesies received from Messrs. Sheilds and Carroll on the occasion of the visit to Harvard Bridge.

Mr. Swan offered the following motion, which was adopted : Whereas, the clock which was recently presented to the Society is arranged in the twenty-four hour system, that, as an experiment, the Secretary be authorized to use the twenty-four hour system in the notices of the Society until otherwise instructed by the Society.

On motion of the Librarian, the sum of $65 was appropriated for the renewal of subscriptions to periodicals and for binding.

The first paper of the evening, entitled "Construction of Farm Pond Conduit," by Henry H. Carter, was then read by Mr. Stearns in the absence of the author, and was discussed by the President and Messrs. Folsom, Hall, Smith and Stearns.

Mr. Richard A. Hale exhibited a Berrenburg Rotary Pump, and read a paper giving the results of a test made by him of its efficiency.

Mr. Frederick Brooks read portions of a paper prepared by him on "Time Reform," with special reference to the twenty-four hour system of reckoning time.

[*Adjourned.*] S. E. TINKHAM, Secretary.

WESTERN SOCIETY OF ENGINEERS.

OCTOBER 10, 1888:—The 251st meeting was held, Mr. S. G. Artingstall in the chair.

The minutes of last meeting were approved.

Mr. Levis Passmore Pennypacker, Assistant Engineer U. S. Construction Company, Chicago, Ill., was proposed for membership.

The resignation of Mr. C. F. Carl Binder, of Cleveland, who proposed to join the Cleveland Society, was received.

The following financial exhibit is compiled from reports of Secretary and Treas-

urer: Receipts since last meeting, $49.50; cash on hand, $107.82; bills paid, $30; bills reported, $240.50.

The Secretary presented written discussions of Mr. Wisner's paper upon "Levels of the Lakes as Affected by the Proposed Lake Michigan and Mississippi Waterway" from the following parties:

Prof. F. M. Haupt, of Philadelphia; Mr. Clemens Herschel, of Holyoke, Mass.; Prof. J. B. Johnson, of St. Louis, Mo.; William Pierson Judson, of Oswego, N. Y.; Walter P. Rice, of Cleveland, O., and D. Farrand Henry, of Detroit, Mich. These papers were read and discussed and the Secretary authorized to compile the same with suitable explanatory matter for publication. It was announced that other contributions were expected.

[*Adjourned.*] L. E. COOLEY, Secretary.

CIVIL ENGINEERS' SOCIETY OF ST. PAUL.

OCTOBER 1, 1888:—The October meeting of the Society was held at the Hotel Ryan, President Loweth in the chair; 12 Members present.

Upon ballot Mr. J. D. White, City Engineer of Fargo, was elected Member of the Society.

The form of contract for buildings as recommended by the National Association of Builders was brought up for discussion but laid over to the next meeting of the Society.

A paper was read, prepared by the President, upon some tests of angle bars made by him in 1887, the results of which tend to give information upon the influence of rivets and rivet holes in such members. The paper was illustrated with drawings showing members tested and the fractures.

Mr. A. Münster followed with a paper upon "The Highways and Railroads of Norway." Mr. Münster gave an interesting sketch of the general topographical features of Norway and then described the national wagon roads and the railroad system. The paper was illustrated with plans of the more important bridges and photographs of the scenery along the railroads. The views showed some examples of striking railroad location and gave some fine pictures of the country.

[*Adjourned.*] GEO. L. WILSON, Sec'y.

ENGINEERS' CLUB OF KANSAS CITY.

OCTOBER 1, 1888:—Regular meeting held in Y. M. C. A. building, President Knight in the chair; 14 Members and 5 visitors present.

Minutes of the previous regular and executive committee meetings were read and approved.

On a canvas of ballots, John M. Walker, S. H. Yonge and H. H. Filley, were declared elected as members, and S. P. Maybach as Associate Member.

The Secretary announced that arrangements had been completed, by which the Club would have the exclusive use of a small furnished room in the Y. M. C. A. building for a library, and of the adjoining two rooms of Prof. Fulton for meetings the first and third Mondays of each month for $15 per month.

It was stated that papers had been promised for nearly every meeting up to March.

A letter from Mr. C. R. Taylor, of Philadelphia, was read, describing a new patent for street pavements.

Proceedings of the American Society of Civil Engineers and New England Water-Works Association had been received for the library, and Mr. G. W. Pearsons promised a set of the proceedings National Water-Works Association.

Mr. A. J. Mason read a paper entitled "The Complete Sewerage of Kansas

City," which was discussed by Messrs. G. W. Pearsons, Gillham, Knight, Kiersted and Allen.

C. S. Clarke was proposed as Associate Member by W. D. Jenkins and B. L. Marsteller.

[*Adjourned.*] KENNETH ALLEN, Secretary.

MONTANA SOCIETY OF CIVIL ENGINEERS.

OCTOBER 20, 1888:—The regular monthly meeting was held at the office of Mr. E. H. Beckler, Chief Engineer Montana Central Railroad, at 7:30 P. M., Mr. Beckler, Second Vice-President, in the chair. Those present were Messrs. Haven, Beckler, Kelly, Farmer, Herron, Foss, Ellison, Goodridge and Keerl.

The written application of F. J. Smith for membership in the Society was received and ordered filed, to be acted upon through letter ballot. Application endorsed by Messrs. Herron, Ellison, Foss and Farmer.

Messrs. Geo. A. Foss, J. H. Farmer and John Herron were appointed a Committee upon Highway Bridges, to act in conjunction with similar committees of other societies, who are to endeavor to promote the movement looking to a reform in the matter of highway bridges.

The Librarian reported having been in correspondence with officers of the *Railroad Gazette* relative to securing for the Library of the Society the back numbers of the JOURNAL OF THE ASSOCIATION OF ENGINEERING SOCIETIES. He stated that while the early volumes of the JOURNAL were scarce, the Society now had the opportunity of securing the complete set, and as he deemed it would be a most valuable acquisition to the library, he hoped the Society would determine upon their purchase. On motion, carried unanimously, the Secretary was instructed to secure for the Society's library all the back numbers of said JOURNAL, and to ascertain to what extent and at what cost the numbers from 1 to 5, inclusive, of the current volume can be furnished members who may desire to secure the complete volume.

The chair read a letter from Col. J. T. Dodge, relative to his removal from Montana, and his desire to withdraw from active membership, as provided by Art. IV., Sec. 5, of the By-Laws. On motion, carried, the withdrawal of Col. J. T. Dodge from active membership was allowed.

On motion, carried, that the Nominating Committee, as provided by Art. V. Sec. 3 of the Amendments to the Constitution, shall be elected by the meeting—the following were placed in nomination for such Committee: Messrs. W. A. Haven, John Gillie and A. E. Cumming, and, upon motion carried, were declared elected.

The Chair called the attention of the meeting to the dangerous crossing of Main street at Sixth aveuue in the City of Helena, as proposed by the Motor line, suggesting the subject as a proper one for discussion by the Society.

Mr. J. H. Farmer, Chief Engineer of the Motor line, stated the grade and alignment of streets at the proposed crossing,upon which data the meetiug entered into a general discussion at some length of the feasibility and the advisability of the Motor line bridging Main street, that street being approached from either side by steep descending grades. The paper for the evening precluding further time being given to this disscussion, Messrs. W. A. Haven, Geo. O. Foss and E. H. Beckler were appointed a Committee to consider and report at the next meeting upon an overhead crossing for the Motor line at Main street and Sixth avenue.

Mr. E. O. Goodridge, engineer in charge of the north end of the Wickes Tunnel on the line of the Montana Central Railway, read a paper upon the "Ingersoll Rock Drill," illustrating the same with sectional drawings. After describing the

drill in detail, Mr. Goodridge entered upon a general description of the work it had accomplished at the Wickes tunnel, but recently finished.

After a discussion of the paper at some length it was on motion referred to the "Committee on Topics" for report at the next meeting upon the advisability of its publication.

The communication from Mr. Geo. O. Foss, relative to the difficulties encountered in endeavoring to define the locus and ownership of mineral locations from County Recorders' records, was upon motion returned Mr. Foss with the request that he present a paper upon this subject at the next annual meeting of the Society.

Meeting adjourned to meet November 17th next at same time and place.

J. S. Keerl, Secretary

ASSOCIATION OF ENGINEERING SOCIETIES.
ORGANIZED 1881.

Vol. VII. December, 1888. No. 12.

THE DAM OF THE CAMBRIDGE WATER-WORKS ON STONY BROOK.

BY WILLIAM S. BARBOUR, MEMBER OF THE BOSTON SOCIETY OF CIVIL ENGINEERS.

[Read June 20, 1888.]

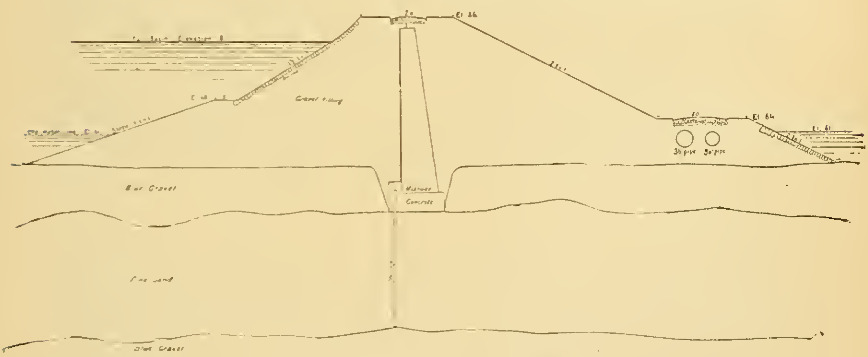
Having been invited by your President, I have prepared some notes describing the work at the dam and basin at Stony Brook, recently built for the Cambridge Water-Works; also some of the difficulties encountered and the methods adopted to overcome them.

The location of the new supply lies partly in Waltham and partly in Weston, and is known as the Stony Brook supply. It is nearly eight miles from Fresh Pond, which is connected by a line of 36 and 30-inch pipe.

The source of Stony Brook is Sandy Pond in Lincoln. There are numerous other branches, among them the Hobbs Brook, quite, if not equally, as large as Stony Brook, with its source in Lexington, Cherry and other brooks without names, the whole draining a territory covering an extent of about 21 square miles. After the surveys were made and temporary locations for the site of the dam were selected, lines of borings were made to determine the precise nature of the bottom on which the dam was to be erected, and also the best and most favorable site. You will observe that this was very important, as all the future work was dependent upon a careful and judicious selection of the site. Two kinds of borings were made. The first by driving a one and one-half inch iron tube with heavy weights, then washing out the material from inside the tube with water forced down with a force pump, through a smaller tube inserted in the larger, the water flowing out of the larger tube and bringing up the material with it. The other method was sinking a tube of 5 inches diameter, the interior of core being removed with a sand pump. Samples of all the above described borings were collected, placed in glass tubes and kept for comparison, and upon which the final character of the foundation was adopted. The results of the borings, which were carried down to a depth of, in places, 75 or 80 feet below the bed of the stream, revealed the unwelcome fact that the underlying strata below the surface crust, which was from 4 to 22 feet in thickness, was a bed of very fine sand extending to a great depth, a very undesirable and dif-

ficult substance to build a dam upon. This surface crust was very uneven, and it was decided to be necessary to go through it to the sand bed and drive sheet piling into the sand as deep as it was possible. The size of the sheet piling adopted was 8 inches thick and of varying lengths of from 10 to 30 feet, with tongues or splines 1½ by 3 inches in width. As this piling was very heavy and probably the largest and heaviest ever driven in this vicinity, it became necessary to provide special machinery for driving it. The contract was so drawn as to provide, if necessary, a steam hammer and the use of a water jet if required. A steam pile hammer, made by the Cram Brothers of Detroit, was at last found which it seemed would fill the requirements of the case, and one was secured by the contractor for this work. Its weight was 5,500 pounds, with stroke of 40 inches capable of being run 75 to 100 blows per minute. The ordinary and actual use made in practice was 60 to 75. The hammer worked in an iron frame about 8 feet long, which in turn was fitted to slide up and down in the gins of an ordinary pile driving machine. Steam was supplied through a flexible hose from boiler standing on the bed frame of the machine. The operation of driving was as follows: The pile being hoisted into the gins, the frame and hammer being raised sufficiently high to receive it, the frame was then lowered on the head of the pile, the bottom of the pile being secured between guides in the usual manner, and properly dogged and wedged, the point of the pile being sharpened so as to hug up and shod with wrought iron plate bent to fit, the driving was commenced, the blow being transmitted through a short follower about 18 or 20 inches long. The followers were used up quite rapidly as the blows were rained thick and fast upon them, the pile in scarcely any case moving more than ½ to ¾ of an inch to a blow. The sand was very hard to drive into, and when dry or free from water was almost as hard as a rock; attempts made to drive into it without shoeing with iron, made sorry work of it, the bottom of the pile being broomed up for 5 or 6 feet so as to appear like a bundle of pack-thread. Other difficulties and obstructions were encountered, such as boulders and streaks of hard pan, some of which had to be dug out by going to considerable depths. The use of the water jet in connection with the driving proved exceedingly useful in cases when in driving, the sand being dry, would become so compact that no amount of pounding with the hammer would move the pile; then the water jet, which consisted of a stream of water under pressure through a hose to which an iron pipe ¾ inch in diameter and about 20 feet long was attached, would be run down along side of the pile, the force of the water escaping at the open end of the tube loosening up the sand and opening a way for the pile, which would then start quite easily under the blows of the hammer. Then sometimes a boulder would be in the path of the pile, and stop its progress. The jet would then be put down a little way outside of the stone, forming an opening by washing away the sand, and allowing the stone to roll away into the hole formed and leaving a free passage for the pile. Many difficulties and discouragements were encountered, and there were times in the progress of this part of the work when it seriously looked as though the sheet piling would have to

be abandoned. At first the men in charge of the machine, not being accustomed to it, did not understand how to run it, and the packing from the steam joints was frequently blown out. An urgent letter to the inventor of the machine stating that if he desired his machine to be a success in these parts he must come on and instruct us how to use it was promptly heeded, and our men soon became familiar with it. At another time the difficulties were so great that the contractors refused entirely to go on, saying it was an impossibility to drive the piles. Feeling the great importance of this part of the work, the machine and gang were taken in hand by the engineers and inspector, the work carried on by day labor, until the obstructions, after much patient labor and persistance, were overcome, and the fact demonstrated that patience and perseverance would accomplish this work (and also at an expense not exceeding the contractor's prices). The machine was again taken in charge by the contractor, and from this time the work proceeded regularly, though at times very slowly, and there now exists a tightly driven row of sheet piling extending the entire length of the foundation of the dam, some 650 feet. Where the hard bottom came within 30 feet of the surface of the sand, they were driven into it; and where not, they were driven about 30 feet—an extraordinary and difficult thing to do, and, so far as the writer is aware, was never before accomplished in this vicinity with sheet piling of such length and thickness. After the piling was in place the tops were cut off to near the level of the sand, and were inclosed in a bed of concrete 12 feet wide and 4 feet thick, stepped down at intervals to conform to the varying depths of the trench. Upon this



Section of Stony Brook Dam.

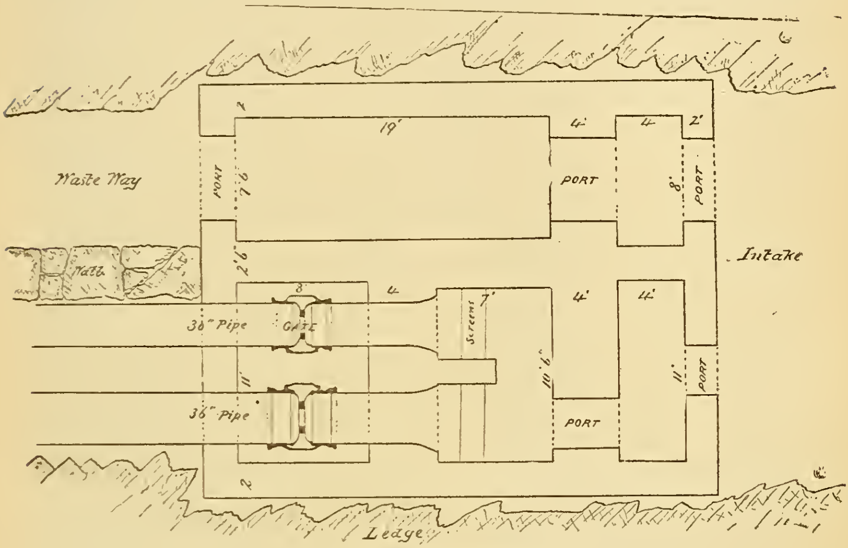
base of concrete there was erected a core wall, 8 feet in thickness at the bottom, brought up to about the natural level of the bottom of the old pond, and from this level to 3 feet below the top of the dam, battering on the down stream side to 3 feet in thickness. This wall was composed of two thin walls, one on each side, laid with stones of large size obtained from the basin and vicinity, laid solid in cement with the space between these walls filled with small stones placed in layers not exceeding one foot in thickness, the interstices between being filled with grout or liquid cement. The up-stream face of this wall was smoothly plastered with clear cement. This wall in the highest part measures 50 feet. It was

feared by some that from its great height and its resting on a bed of sand that it might settle and crack. An iron pipe was inserted in the foundation and carried up on the outside of the wall to the top, upon which levels were taken from time to time. As yet no settlement has occurred, and it is now thought that all danger on that score has passed. As the wall was completed the remaining portion of the trench was filled with selected material carefully puddled and tamped with heavy rammers, or rolled with grooved rollers. The earthwork of the dam will average about 180 feet thick at the base and was carried up in layers of selected material (all stones greater than 3 inches in diameter being excluded) not exceeding one foot in thickness, thoroughly wet and rolled with loose wheeled sectional rollers to a thickness of about 6 inches. At elevation 64.00, there is a berme on the lower side 20 feet wide, and at 68.00 one on the upper side by which the base is reduced to 96 feet. The outer face is carried up with a slope of 2 horizontal to 1 vertical and is covered with loam and sodded in part and seeded. The up stream side, to the level of the berme is carried up with a slope of 3 to 1, and from this level is made 1½ to 1, with a slight curve at the top to prevent the wave action from washing the top of the dam. The whole face of the up stream side is paved with heavy field stone 18 inches thick laid on a bed of small or cracked stone. The top of the dam is 20 feet wide and has a walk in the centre 8 feet in width, while the borders are covered with loam and seeded. The north end of the dam was entered into the bluff about 50 to 75 feet, the up stream side being turned with a curve of 100 feet radius, thus lapping well on to the up stream side of the bluff. A curve was also made on the down stream side, thus making the thickness at this point more than double that at any other; this, owing to the porous nature of the natural hill, was thought necessary.

At the southerly end of the dam a much better state of things existed, the material there being ledge, and opportunity was taken to locate there all the appurtenances for collecting, distributing and wasting the water, for which ample provision has been made. A channel 30 feet wide and about the same depth was first blasted out and the gate chamber afterwards located in the excavation about in line with the centre of the dam.

The chamber is built of cut stone, being largely of granite from Keene and Mason, N. H., laid in courses of about 2 feet rise each, the exterior faces being quarry faced, with arris lines around the edges of each stone. The chamber is divided into five smaller chambers, by heavy partition walls all of cut stone, and for the following uses: The right hand up stream corner is the receiving chamber from which the water is directly received from the pond, and contains the three sluice gates for delivering the water to the other chambers. The next, or middle chamber, contains the screens, and the bell-mouthed ends of the pipes which lead to the city. The next chamber contains the stop-gates, there being one of 30 inches diameter and one of 36 inches. On the opposite side is the waste way, which is to be used when more water comes than can well be passed at the overfall, or for purposes of emptying speedily or otherwise the pond. This is divided into two chambers, the first containing the stop-plank and the large sluice gate.

The dimensions of these gates are as follows : For waste way 5 feet by 6 feet, and the three above referred to as feeding the consumption or water delivered at Fresh Pond are each 3 feet square. The water from the waste way is discharged through an arched sluice extending about 60 feet under the dam and discharging at the base on the down stream side. Adjoining the chamber and in continuation of the dam is the overfall. This is constructed of dressed granite and has a water way of 40 feet in width. It is 5 feet thick at the crest or top, and 13 feet at the bottom, 10 feet high and rests in part upon the ledge. The level of the crest is 5 feet below the top of the dam. The overflow has been spanned by an iron latticed arched truss foot-bridge designed by the writer. This



Plan of Gate Chamber.

structure was erected by the Boston Bridge Works in a very satisfactory manner, and is a very neat and graceful structure. From the overflow the water passes between the walls of the overflow channel spaced 60 feet. These walls are made of granite from 6 to 10 feet thick, coped with dressed granite coping, the space between the walls being paved with heavy stone paving. The wall is continued around and extends up Summer street about 300 feet forming a retaining wall to hold the embankment and prevent the water, when the pond is full, from overflowing Summer street. On the top of the gate chamber previously described, has been erected a gate house of brick with New Brunswick free stone belt courses and trimmings of a light yellow shade which form a pleasing contrast with the red brick. Over the door or archway to the porch is a tablet with the inscription, "Cambridge Water-Works, 1887." The interior of the house is finished with face brick, the belt courses of light stone coming through and show-

ing on the inside. The roof is carried by two trusses made of hard pine, and the roof covering is also of hard pine boards matched and beaded and forming the interior finish, the whole finished with oil and shellac. This gate house contains all the hoisting gear for the six gates in the chamber below as well as for the stop plank, screens, etc. From the gate chamber start the two pipes leading to Fresh Pond, one a 36-inch. extending about one mile to the pumping main of the Waltham Water-Works, where a branch is provided to connect with and supply them if they should desire. From here the pipe reduces to 30 inches, and continues through the Waltham Cemetery, private lands and highways, to Fresh Pond, where it passes through a small gate house on the border and thence out into the pond, terminating there in a fancy fountain or an open end as desired. The other pipe extends only across the dam where it unites with the 36-inch. On the first mile of this line, which passes through private lands, a way was graded requiring in some places cuttings of 25 to 28 feet in depth, and fillings of 15 to 25 feet. At intervals of about one mile gates were placed, and the whole line has been fitted with air valves on the summits, and blow offs on all the low points. The whole distance to Fresh Pond is about eight miles, and with the arrangements provided repairs can be made if necessary without emptying more than one mile of the pipe. The basin which has been prepared in connection with this dam extends about one and a quarter miles up the stream, is about one-quarter mile wide, with bold and rocky shores. The available depth of water when full is 20 feet, and it will contain about 354,000,000 gallons. The bottom and sides have been carefully grubbed and cleaned by removing the mud from the bottom (of which about 80,000 yards were taken out) or covering with gravel, removing the trees, stumps and other objectionable matter. While this basin is quite small it is a very good one, there being practically no shallow water. The possibilities of a further development of the stream are also good. Four miles further up the stream is Beaver Pond, where a basin can be built with a depth of water of about 15 feet and a storage capacity of about 680,000,000 gallons, and on another branch the Hobbs Brook, a basin can be built of an equal capacity, though it is not expected that these or either of them will be needed for many years. It was thought best to secure the possible sites for dams to create these two basins, and this has been done. For supplying Roberts' mill with water during the construction of the works a No. 9 Blake steam pump was set up near the mill, a suction laid to Charles River, the mill piped and water to the amount of about 300,000 gallons daily have been pumped at the expense of the city of Cambridge.

The work of blasting the ledges and cleaning the trees was performed under a contract with Messrs. Scully & Gill; the work of constructing the dam and basin by Messrs. Henry H. Pike & Son; the gate house by Marshall N. Stearns; the gates and valves by the Coffin Valve Company; the pipe and special castings by Messrs. R. D. Wood & Co.; grading the pipe line, Thos. F. & J. J. Maney; while the larger portion of the pipe laying and work at Fresh Pond has been done under the charge of Hiram Nevons, Superintendent of the Cambridge Water-Works. In the plan-

PLATE 3

HELIOTYPE PRINTING CO., BOSTON, MASS.

STONY BROOK DAM—CRAM'S STEAM PILE HAMMER.

ning and construction of so large and important a scheme of works many questions have arisen, and the services of our consulting engineer, Mr. N. Henry Crafts, have proved of great value, as well as those of Mr. Lewis M. Hastings, who designed most of the structures, and Mr. Geo. Davis, who acted as resident engineer in charge of the construction, assisted by Benj. F. Bates and many others who have been employed on the works.

DISCUSSION BY JOHN R. FREEMAN.

Percolation Through Embankments.

There came up in my practice last October a case which will, I think, be of interest to all of us who have just listened to the very interesting and instructive paper of Mr. Barbour, as bearing upon the question of percolation through the gravel banks of the pond adjacent to his dam, and is instructive for comparison with the two carefully and elaborately constructed embankments that have just been described to us, as illustrating the stability of one hydraulic embankment which was "reduced to its lowest terms."

I refer to the embankment of the Nashua Manufacturing Company's canal, which conducts some 600 cubic feet of water per second from the Nashua River down through the woods a distance of about two and a quarter miles, and delivers it to the water wheels of the mills, where it develops some fifteen hundred horse-power.

This canal was first built about sixty years ago, in days before hydraulic engineers had much to do with such matters, and instead of following a straight line across the broad and sandy plain, as would be done to-day, its builders added fifty per cent. to its length, and followed the upper edge of a moderately steep sand and gravel bluff which marks the outline of a terrace lying back 500 feet or so from the river, digging into the top corner of the bluff and depositing the excavated material on the side toward the river, thus forming the bank. Thus for a distance of a mile and a half the canal and the embankment are of the general form shown in the upper sketch.

Instead of a depth of 4 to 5 feet above the water line, such as we usually consider necessary in this latitude for preventing injurious action of frost, there are here long stretches where the height of the embankment is but a little more than two feet above the water; though it may be stated that at first the water in the canal was not carried so high by about two feet as in later years. The thickness of the bank is moderate, and instead of being composed wholly or in part of impervious material, it is composed wholly of material which would serve well for making a filter.

There is not a trace of clay in its composition; indeed no clay is found within a dozen miles from there. The natural ground underlying the canal contains in some places layers six inches to a foot thick of gravel coarse as hen's eggs mixed with peas. The embankment was built of gravel and sand—the finest and closest of which would make good mortar sand—and the builders put in no sheet piling, puddle wall, or priming of any kind.

Yet this embankment thus built has kept tight and done good service summer and winter, for sixty years; and, with three exceptions, there have never been breaks or dangerous leaks.

The Nashua River has its course largely among meadows, and in a country which, though hilly, is not mountainous; and its power is so thoroughly utilized throughout its course that many mill ponds exist which, as a whole, make the course of the water rather sluggish, and thus the mud carried in suspension, or the amount of silt deposited down here at Nashua, even at times of freshet, is small—very small in comparison with that in the neighboring Merrimack.

Yet we know that samples from natural river waters which in their bed appear very clear are made vastly more clear by careful filtration; and makers of fine writing paper know how few weeks or days it takes a good sand filter to become clogged when supplied with even ordinarily clear river water.

The secret of the permanence and tightness of this embankment, if indeed so plainly apparent a fact may be termed a secret, is that the whole wetted interior surface of this canal has become coated with a somewhat slimy deposit, and the sand and gravel of its bed impregnated and filled to a depth of frcm one to several inches with this somewhat slimy, muddy, silt-like deposit which practically prevents percolation to any noticeable extent: and with regard to the fact that although the top of the embankment is in places but two feet above the water line it has not suffered more from frost, I think we may consider the reason evident in the fact that since this thin coating of clogged sand stops the filtration of water, all that portion of embankment lying outside it is as free from standing water as the ballast of a railroad embankment, and therefore no more liable to upheaval from frost.

I intimated a moment ago that there had been three breaks in this embankment. The first two of these occurred thirty years and more ago, and it is not now possible to learn their cause with certainty. The third break occurred in October last, and it was in superintending the repairs on this that my intimate acquaintance with this structure came about. Hastily summoned to Nashua, I found that 150 feet of the embankment was totally washed away and the bottom gouged out to 9 feet below the bed of canal, and that for a further distance of 500 feet the inner half of the embankment had been cut away by the swift current of the escaping water, and that the bed of the canal was more or less gullied out for a total distance of 1,250 feet.

There was no eye witness to this catastrophe, as it occurred in the woods a mile or more away from either the mills or the head gates. The sudden lowering of the water was noticed at the mill, and the gate-keeper notified by telephone, "Something has happened somewhere; shut down quick!" By the time men arrived the canal was empty, and the break completed.

A careful study of the surroundings, the earth at edges of break and the débris, and a very careful examination of the scars on bushes and trees in front of the break, made me confident that the hole progressed rapidly from small beginnings, and that in all probability the cause of the break was not the loose porous character or the small thickness of the embankment, but that the cause was a muskrat. This was a spot where muskrats abounded, and even in the remaining bank close by the break a rat hole was found extending half way through.

PLATE I.

HELIOTYPE PRINTING CO., BOSTON, MASS

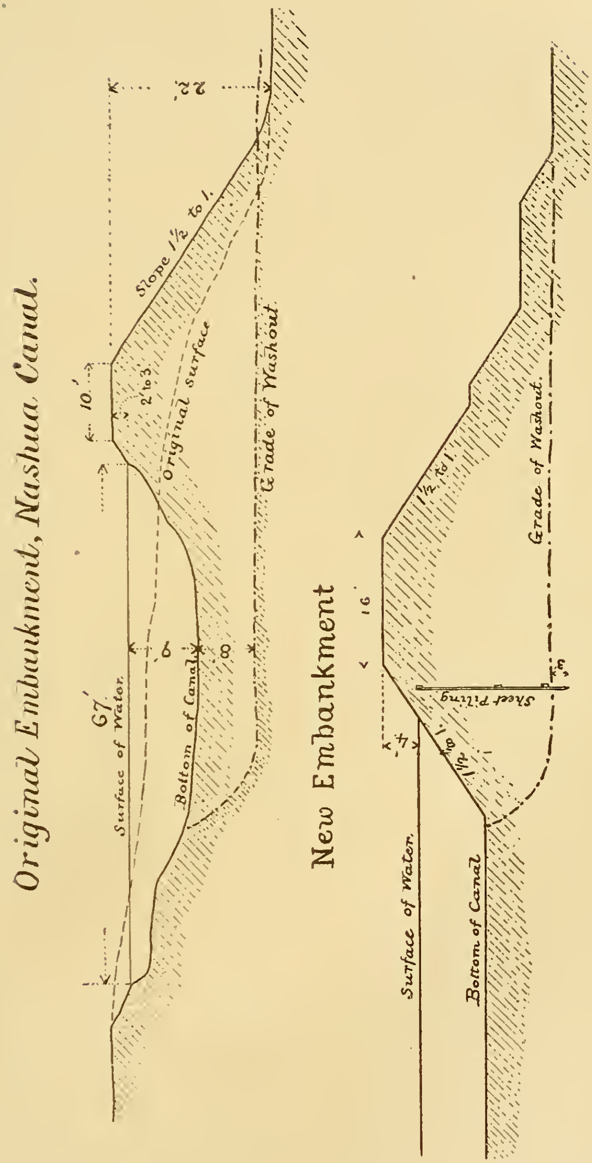
STONY BROOK DAM.

PLATE 2.

HELIOTYPE PRINTING CO. BOSTON, MASS.

HELIOTYPE PRINTING CO. BOSTON, MASS.

STONY BROOK DAM—CORE WALL.


Original Embankment, Nashua Canal.
67'
10'
22'
Slope 1½ to 1.
2' to 3'
Original surface
Grade of Washout
Surface of Water.
Bottom of Canal
9'
8'
New Embankment
16'
1½ to 1
4'
3'
Sheet Piling
Grade of Washout.
Surface of Water.
Bottom of Canal

Concerning the repairs, I will take time to mention only what bears on the matter under discussion, viz., the percolation through gravel.

During the three weeks taken to complete the repairs the gates at head of canal were not tightly closed, and thus a stream of water about 10 feet wide by 6 inches deep continued flowing down bed of canal with a velocity of about two feet a second, and without noticeable diminution of its volume until it reached the point near the break where the erosion and gullying of bed of canal began. Then in going a distance of about a hundred feet all this large quantity of water sank from sight in the porous gravel and completely disappeared.

This shows the leaky nature of the ground with which we had to deal. Probably just below the surface there was one of those strata of gravel coarse as eggs mixed with peas to which I referred in the beginning. Several hundred feet away, out half way to the river bank, I found a stream of clear water quietly oozing up, which I took to be the same as that which was disappearing in the canal.

The mill with its fourteen hundred operatives was idle, while interest and taxes were going on. Its goods were sold ahead and the selling house crying for their delivery; and the first instruction that I got from the agent or manager of the mill was the admonition to bear in mind that each day's complete idleness of the mill meant a loss of $500. Thus we had to work lively; and though all things were not done just as I would have preferred, we found our main warrant for the course pursued in that we knew we were building a much better embankment than the one that had stood for so many years.

A section of this new embankment built is shown in the lower sketch. The material was wheeled over from the in-shore bank. It was almost entirely of material which would have made excellent coarse mortar sand, and was deposited in layers about one foot thick, leveled off and thoroughly wet down by streams from 2-inch hose and a large steam pump; and that part of the bank lying within 3 or 4 feet each side of the piling was thoroughly rammed as deposited.

A line 700 feet long of 3-inch northern pine sheet piling was placed as shown in the sketch. The bottom of this was driven only 3 feet below the surface left by the washout. Not a particle of clay went into the embankment, for none could be procured unless hauled by carts from the railroad some little distance through the woods. I realized fully in building this embankment that what we had constructed was so far really *only a gigantic filter!*

The first question therefore was, how to clog this filter, and as I was called away from Nashua by other work I left orders that mud or muck which had in course of years been deposited to a depth of several inches in a large pool on the in-shore side of the canal, and also along the in-shore bank of the canal itself, be scattered and deposited in bottom of canal at the place referred to above, where the stream running down along canal sank into the gravel and disappeared from sight, and that then water be let in very gradually, raising its height only about a foot each day, and that meanwhile men with shovels be strung along the in-shore bank of canal upstream from the break who should scrape up the deposit of mud and silt from the in-shore part of canal bed

and throw and scatter it in the water, thus keeping the water turbid as possible, meanwhile maintaining a very sluggish current through the canal.

Considering their anxiety to get the mill started, it is not strange that in the absence of the engineer an abridgment of this process was tried, and since the embankment looked good and strong the canal filled at once half or two-thirds full.

In the course of a few hours water filtered through the embankment in such quantities as to frighten them, and the canal was emptied quickly as possible. From what I could learn on my return, I got the impression that the amount filtering through the new embankment, oozing from its outer face, and showing itself in a stream flowing at foot of slope, was about equivalent to a stream three feet wide by eight inches deep, with a velocity of three feet per second; while, of course, some considerable quantity passed away under ground and was not visible.

After drawing off the canal again, a layer composed of a mixture of loam and muck and mud was puddled in on bottom of canal, and then when filled the second time it was filled gradually and the water kept as turbid as possible while filling, as previously urged.

A considerable quantity of water still filtered through, though very much less than before, but ran clear and grew less day by day, and even a fortnight after filling I found the visible percolation flowing along outside of new bank amounted to a stream 2 feet wide by 2 inches deep, flowing about 3 feet per second, and down along the old and uninjured bank there was still half a dozen places where water came out almost like a boiling spring, say 20 to 40 gallons per minute. At each of these there was a little cone of fresh, clean sand containing 1 to 5 cubic feet, and I confess they looked rather startling; but the water then flowed perfectly clear and these "springs" diminished day by day.

These leaks in old embankment were undoubtedly induced by the washing off of the coating of slime and mud from bed of canal in spots by the rapid current toward break at time of washout, and perhaps was aided by the cracking of this coating when dried by the sun during the time the canal was empty.

All these leaks in the old bank and all the visible filtration from the new bank ceased entirely in the course of two months or so, and I am told that to-day the canal is tight as one could wish.

In the above work I was guided and encouraged by things I had seen during my engineering experience with the Essex Water Power Company, at Lawrence. Mr. Mills desired to deepen the main canal slightly in places, and the cheapest way to do this was to plow up the bed and then let the current wash the loosened sand out through the drain gate.

Each time this was done there would, soon as the canal was filled, be trouble from water filtering into the basement of an adjacent mill which stood considerably below the water level in the canal, and uneasiness in the minds of some persons was thereby caused; but it was found this leak would gradually cease, and the whole thing was repeated so many times as to leave little doubt but that the leak was due to breaking the

skin on the bottom of the canal, and the stoppage of the leak due to clogging the fresh surface by the silt carried by the river in suspension; but the Merrimack carried much more silt than the Nashua river.

I have mentioned all this for its bearing on the question which some one has raised regarding the percolation or leakage through the gravel banks of Mr. Barbour's reservoir, and the implication that perhaps these leaks might be a source of danger.

In view of the facts I have stated, may we not feel confidence that these banks of the Stony Brook Reservoir will continually grow tighter? I have myself never seen Stony Brook or its embankment, but though it might be thought that Stony Brook was too clear to clog a filter like this, does not Mr. Barbour's statement of the quantity of mud which he dug out from its bed at the site of the reservoir show that there is some such matter in suspension, and that results similar to those at Nashua may be expected?

LAWRENCE DAM ACROSS MERRIMACK RIVER.

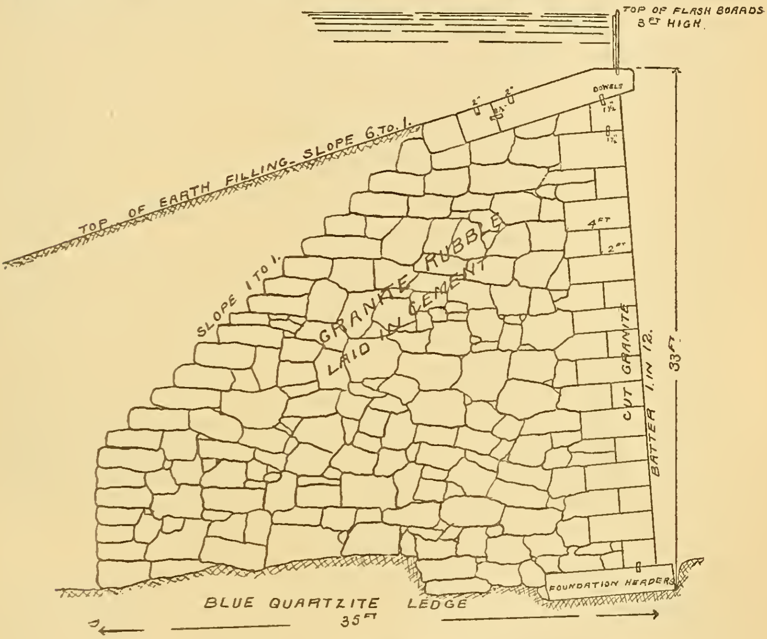
By Richard A. Hale, Member Boston Society of Civil Engineers.
[Read June 20, 1888.]

The Essex Company's dam across the Merrimack River at Lawrence was commenced in July, 1845, when excavation was begun. The first stone was laid September 19, 1845, and the last stone September 19, 1848, three years being taken for its construction. It is a substantial structure of stone masonry, running obliquely across the river, and has a total length of 1,629 feet, including the wing walls. The length of the north wing wall is 405 feet, and the south wing wall is 324 feet, these walls extending to meet the walls and guard locks of the canal. The overfall is built on a curve, and the length of overfall is 900 feet, with the middle ordinate 14.98 feet. A section of the overfall is shown in the accompanying sketch. It is about 35 feet broad at the base, and 12½ feet at the lower end of the coping crest stone. It has an average height of 32 feet, and a maximum height of 40½ feet. The front face has a batter of 1 in 12. The cap stone is level for about 3 feet, and then slopes 1 foot in 3 feet for 12 feet beyond. The back is then stepped off at an angle of 45 degrees. The face of the dam is all dressed stone, and the remainder of the dam is solid rubble work.

The foundation was prepared by blasting out a trench in the rock, and cutting away all loose material till solid rock was reached, thus forming a series of steps. The first course of the foundation is composed entirely of headers, and the next course all stretchers doweled to the foundation course. The headers and stretchers of each course are dovetailed together, and the capping stones are doweled to each other and the next course below. The dowels at the top are set in brimstone, and in other portions of the dam are set in the ordinary cement used about the dam. On the front side the structure is carried up with split granite stone, hammered bed and build, the vertical joints being ⅜ inch, and laid in course 16 inches to 24 inches rise. The remainder of the masonry was of rough stone, laid as compactly as it was possible to lay them without hammering, well bonded together, and to the front courses by stones of

large dimensions. The walls on either side of the overfall are carried up 10 feet higher than the crest, and extend around to meet the walls of the canal.

In the construction, coffer-dams were built inclosing certain portions of the river, and the walls brought up to certain heights, the water in the meantime being allowed to flow over other parts of the dam. New coffer-dams were then built inclosing those portions not built, and the water was permitted to flow over the parts completed, which were left with a smooth, even surface and covered with rough sheathing of plank. The deepest portion of the river was first inclosed and brought up to the level of the rest of the bed, and then carried up as described.



Section of Lawrence Dam.

A portion near the principal arch of the bridge below the dam was left low to allow the passage of rafts and logs till near completion, when navigation was closed for five months. The following is taken from specifications which were closely followed in building the dam.

The lower front course is to be entirely of headers, not less than 18 inches deep and not less than 8 feet long, let into the rock or bolted to it in such a way as to prevent sliding. They are to project one foot from face of wall, and are to be laid in level stretches lengthwise of dam as long as the uneven surface of rock will permit ; that is to say, 30, 40 or 50 feet or more running lengthwise of the dam to be laid at the same level, then a step made and another level carried on. The front face is carried up with split stone laid in courses, three-eighth inch joint, ham-

mered to a fair bed 2 feet back from the face. Joints are at right angles to face, which has a batter of one inch to the foot. Headers are to run back 4 feet from the face, and to be laid as often as once in 8 foot lengths of course, breaking joints one above the other.

The crest of the dam is to consist entirely of headers not less than 2 feet deep and 9 feet long, hammered to three-eighth inch joints, and projecting 1 foot beyond the face of dam. These headers to slope backward 1 foot in 3, and every stone to be bolted to the stone underneath its lower end by an iron bolt 1½ inches diameter, set in brimstone or cement, according to location.

The stone in the rear of the headers on the crest to be laid as stretchers, and not to be less than 5 feet long, and the headers to be secured to these by iron clamps. Ends of the land wall, where they join the crest, are built of heavy splint granite stone similar to the face of dam.

In the main body concrete may be used instead of mortar to fill the spaces, the stones being smeared with cement.

In the capstones of the dam are drilled two rows of holes 6 inches deep and sufficient diameter in which to insert iron pins 3½ feet long and 1½ inches diameter, to support flash boards by which the water can be raised 3 feet above the crest of dam—the down-stream row of holes is 18 inches back from the face of the dam and spaced 20 inches centre to centre supporting flash boards 16 feet in length. In freshets, when the water rises to a height of about Ref. 42, or 8 feet deep on the crest of the dam, the pressure bends the pins and carries away the boards, thus preventing damage from flowage.

When the water falls in the river the flash boards are renewed and the second row of holes is used for inserting a row of pins, against which flash boards are placed to shut off the water and to allow the scow, used to replace the flash boards, to rest against them while bent pins are taken out and replaced by new ones. The scow is 50 feet long, and is pushed along the line as the boards are renewed all of the way across, or until the water is brought up to a sufficient height.

The total cost of the dam was $250,000.

Material used in construction was as follows:

Rock excavation	1,700 cubic yards.
Masonry in cement	29,000 "
Surface of hammered granite	148,000 square feet.

The contract prices paid at this time were as follows:

Masonry of split granite laid in courses in cement, per cubic foot	$0.20
For hammering the split stone, bed and build, per superficial foot	.08
Masonry of rough stone, from Andover ledges, laid in cement or concrete, per cubic yard	2.00

The above prices include all materials, except cement, which is furnished by the company.

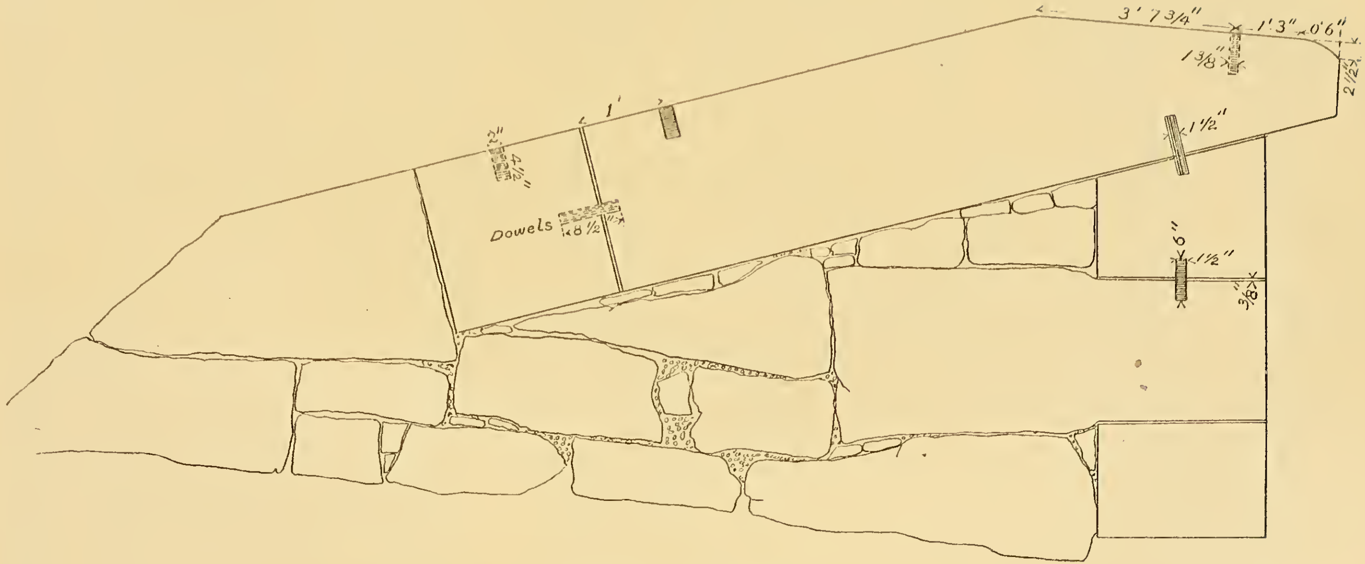
For rubble masonry, laid dry, per cubic yard	$1.75
For excavations in the bed of the river, not solid rock, per cubic yard	.25
For excavation on land, wing walls, etc	.15
For excavation of solid rock, per cubic yard	1.00

The wages of laborers varied from $0.84 to $1 per day. Stonecutters, masons and carpenters, $1.50 to $1.75 per day.

The cement used was principally Lawrence's Rosendale cement from Rondout, N. Y.

The proportions of sand and cement were as follows:

Cement mortar: 4½ cubic feet of cement, 6 cubic feet sand.



Section of Top of Dam.

Lime and cement mortar: 5 cubic feet of cement, 2 cubic feet lime paste, 10½ cubic feet sand.

Cement beton: 4½ cubic feet of cement, 4½ cubic feet of sand, 9 to 12 cubic feet broken stone.

Lime and cement beton: 17 cubic feet of cement, 8 cubic feet lime paste, 48 cubic feet sand, 126 cubic feet broken stone.

A mortar of the consistency of thin cream, composed of cement and water, was used to brush over the surface of the stones where beton was to be laid, to ensure cohesion between the beton and stone work of dam.

Cement mortar was used in setting foundation headers for distance of 8 feet back from the face of the dam, in the rear of the dam for 5 feet back, also on top of the dam and in wet places in dam.

Lime and cement mortar was used in other places.

Cement beton was used behind the granite face of the dam and in wet places in the body of the dam to fill up spaces between rubble masonry.

At the present time there is no indication of any crumbling of the cement about the joints or any change in the structure.

The chief engineer who designed and laid out the structure, including the canal's head gates, etc., was Charles S. Storrow, Esq., of Boston. He was also agent and treasurer of the Essex Company, which position he filled till a few years since, when he resigned, taking a less active part in some respects, but continuing his connection as President and director of the company, which position he now holds. Capt. C. H. Bigelow was the assistant in charge, who had the advantage of considerable experience in masonry previous to his service here.

Too much cannot be said of the skill and boldness of the enterprise at this time when so few similar stone structures were in existence, and the permanency of the work, together with the admirable system of canals, head gates, mill sites, etc., and the general laying out of the city constitute a lasting monument to Mr. Storrow and his associates.

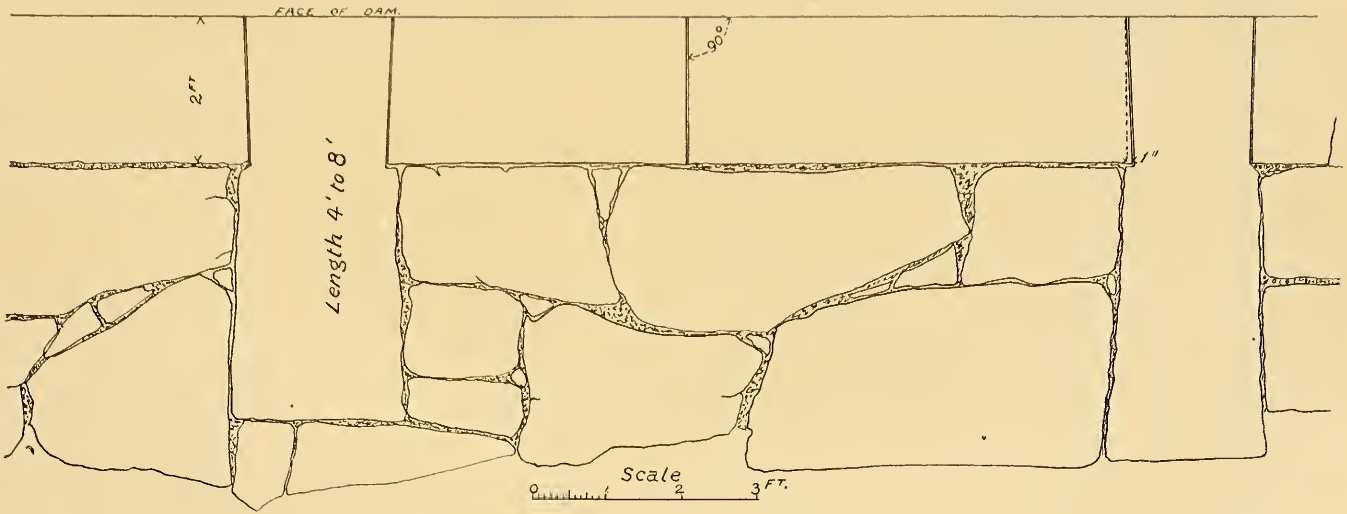
DISCUSSION BY J. R. FREEMAN.

If the hour was not so late, I would like to add a few words to what Mr. Hale has said, and grow enthusiastic meanwhile, for this dam has now stood the frosts and freshets of more than forty years without leaking a drop, starting a stone or opening a crack a hairsbreadth, or costing its owners a single dollar for repairs or protection. It was the precursor of the stone dams at Lowell, Manchester and Lewiston, was completed before the timber dam at Holyoke.

It was built in a day when there were few precedents to guide the engineer in designing such a structure, and it stands to-day, so far as I know or can learn, the most magnificent milldam in the world.

Though built forty years ago the details of carrying out the work, the character of the supervision for securing the best of work form a good guide for the engineer of to-day. Every barrel of the cement was tested, and though, of course, our present improved appliances for such test were not then known, yet the tests made sure of its hydraulic properties.

To Capt. Bigelow, whose training in the engineer corps of the U. S. Army at fortification building had made one of the most thorough



Plan of the Method of Arranging the Common Headers and Stretchers.

masons of his day and generation, much of this excellence was due ; but I can hardly let the occasion pass without a word about its designer and chief engineer, who was one of the charter members of this Society of ours, and whose engineering experience now covers a period of nearly sixty years.

Charles S. Storrow graduated from Harvard in the famous class of 1829, with the poet Holmes, the eminent divine James Freeman Clarke, and the mathematician and astronomer Pierce. With a clear and definite purpose he chose the profession of civil engineering at a time when engineering was in this country yet an almost unknown profession. He went abroad and studied several years in the best schools of France, and when fairly entered on the practice of this profession a half century ago he stood equipped, I doubt not, as the best educated engineer in America.

His designs were all studied in the clear light of science, and as a result have stood the test of time. The water power whose development he superintended stands alone among our great water powers as one where the end and magnitude were clearly seen and correctly estimated in the beginning and continually kept in view, and the details of the design in areas of sluices and sizes of canals all carefully adjusted thereto.

A large share of his attention was so soon diverted from his chosen profession by large financial and business responsibilities, and he seeks to appear so little in the public eye, that though there are those among us to whom his acquaintance and friendship have been for years a continual inspiration, there may be some others among us who hardly realize that he still walks the streets of Boston, a fine example of

> " How far the gulf stream of one's youth may flow
> Within the Arctic circle of his life."

A BRIEF DESCRIPTION OF THE QUINCY DAM.

By Lucian A. Taylor, Member of the Boston Society of Civil Engineers.

[Read June 20, 1888.]

The dam being built by the Quincy Water Company is situated on Town Brook, in Braintree, Mass., one and one-fourth miles above the pumping station and wells of the company on the same stream. The water-shed of 1,000 acres is very largely covered with a growth of hard wood and brush, extending to granite hills, several hundred feet in height above the valley. There is very little tillage land, and it is very sparsely settled. The reservoir, which will cover about 50 acres, is situated on two brooks, and is in the general form of a Y, the dam being about 600 feet down stream from the junction of the two brooks. The general slope of the valley is about one in one hundred, with side slopes generally very steep, from ten to thirty in a hundred. The general direction of the valley is from east to west. The divide on the north side for one-half mile from the dam is a low sand and gravel plain, against which the northerly end of the dam abuts, the level of each being practically the same, and the slope of the plain being about the same as the valley.

The length of the dam (which runs nearly north and south) will be

about 550 feet, and its height 36 feet above the bed of the brook. The width on top will be 20 feet, with outer and inner slopes, two horizontal to one vertical. The inner slope will be covered with a pavement about 2 feet in thickness, and the outer slope and top covered with a layer of loam and seeded.

The embankment is composed mainly of gravel placed in 6-inch layers, watered and rolled with a heavy grooved roller.

About 100 feet of the northerly end of the dam abuts on the steep sand and gravel hill. About 150 feet southerly, in the lower part of the valley, is gravel and sand to a depth of from 15 to 30 feet. The entire southerly slope is a compact clayey material with many large surface boulders. Under the entire base of the embankment the natural soil was excavated to a depth of at least 2 feet, and in the valley to a depth of from 4 to 6 feet. The embankment at the northerly end is stepped into the hill to a depth of from 8 to 10 feet, and commencing 150 feet from the northerly end of the dam widens by a curve to 110 feet on top, where it connects with the original hill.

Across the centre of the valley for a distance of 193 feet along the centre line of the dam there were driven two rows of hard pine grooved and splined sheet piling 7 feet apart, one row of 6-inch on the upper side, and a row of 4 inch down stream. This piling was driven through the sand to a bed of compact gravel and boulders and into the gravel hill to a depth of 35 feet below the surface. The material between the sheet-piling was excavated to a depth of from 15 to 20 feet below the surface to a foundation of compact gravel and almost entirely free from water. This trench was filled with concrete in 6-inch layers. A masonry core wall 7 feet in thickness was built on this foundation and will extend 2 feet above the level of the rollway and 2½ feet thick at the top. The row of 6-inch sheet piling was extended 117 feet, making an angle up stream of 34° 15′ and extending beyond the end of the dam 80 feet. A trench 12 or 13 feet deep was excavated and the piling driven 25 feet below the bottom of the trench to hard foundation. The upper 3 feet of the piling was enveloped in concrete, which extended to the same height as the wall in the main embankment.

Near the foot of the southerly slope and south of the sheet piling are 2 lines of 20 inch cast iron pipe extending through the base of the embankment enveloped their entire length in a masonary wall embedded in a firm clayey foundation extending to a gate house 60 feet up stream from the top line of the inner slope. There is also a line of 6-inch pipe laid between the 20-inch pipes to act as a drain in case of clearing the gate chamber. One line of 20-inch pipe terminates in the centre of the gate house and one line passes through the upper wall and draws from the bottom of the reservoir. All the pipes have valves in the centre of the gate house.

The gate house foundation is 10 feet in depth and 21 feet square. At the level of the pipes the gate house is 20 feet square and 14 feet at the top of the dam, with gate chamber 8 feet square the entire depth.

The upper or reservoir side has an opening 2½ feet wide, extending from a point 8 feet above the bottom of the pipes to a level of the top of the dam. This opening is arranged with iron guides, with composition

faces set in brickwork for the reception of screens and stop plank, so arranged as to draw from the surface of the reservoir or any other elevation. This is to be surmounted by a brick building with granite trimmings. A line of 12-inch pipe will be extended to the pumping station during the present season. The rollway is at the southerly end of the dam and is 25 feet in width, and the overfall stone 5 feet below top of the dam.

The side walls and bottom will be laid in cement masonry and extend to the bed of the brook below the dam.

ASSOCIATION OF ENGINEERING SOCIETIES.

PROCEEDINGS.

BOSTON SOCIETY OF CIVIL ENGINEERS.

November 21, 1888:—A regular meeting was held at the Society's rooms, Boston & Albany Railroad station, Boston, at 19:30 o'clock, President FitzGerald in the chair, eighty-two Members and thirty-two visitors present.

The record of the last meeting was read and approved.

Messrs. Frank A. McInnes, J. Parker Snow, and J. Frank Williams were elected Members of the Society.

The following were proposed for membership:

Henry F. Bryant, of Brookline, Mass., recommended by A. H. French and G. F. Swain; Levi G. Hawkes, of Saugus, Mass., recommended by D. W. Pratt and H. C. Keith; and George A. King, of Taunton, Mass., recommended by Phinehas Ball and W. R. Billings.

On motion of Mr. Howe, the Secretary was requested to tender to Mr. James T. Furber, General Manager, Boston & Maine Railroad, the thanks of the Society for courtesies received on the occasion of the visit to Newburyport.

Mr. F. O. Whitney, for Committee to prepare a Memoir of Henry F. Walling, submitted its report, which was read and accepted.

The Secretary read a communication from Mr. James D. Mason describing the tunnel recently constructed in Milwaukee for pumping the water of the lake into the river for flushing purposes.

Mr. Alphonse Fteley gave a very interesting description of the new Croton Aqueduct, which was illustrated by lantern views.

[*Adjourned*]. S. E. Tinkham, Secretary.

ENGINEERS' CLUB OF ST. LOUIS.

November 7, 1888:—The 295th meeting was held at the Lindell Hotel, being a celebration of the twentieth anniversary of the formation of the Club. There were present Messrs. Bartlett, W. H. Bryan, Engler, Gale, Glasgow, Gould, Holman, Hubbard, Jewett, Laird, R. E. McMath, Thos. McMath, E. D. Meier, Melcher, Meysenburg, Robt. Moore, Mueller, Myers, Nipher, E. C. Parker, R. Parker, Penny, Pond, Russell, J. A. Seddon, Bathurst Smith, Stockett, Sypher, Thacher, Wheeler, Zeller. At 8:45 the members present sat down to supper. After doing justice to the repast, the President called on the Secretary, who read the programme for the coming year, as prepared by the Executive Committee, as follows:

November 7—Supper in honor of Twentieth Anniversary.

November 21—"Smoke Prevention," Robert Moore, C. E.

December 5—Annual meeting. Reports of Officers and Committees. "Condensers for Steam Engines," Prof. J. H. Kinealy, A. and M. College of Texas.

December 19—Address of retiring President, M. L. Holman, Water Commissioner, city of St. Louis. "Changing the Gauge of the Ohio & Mississippi Railway," Isaac A. Smith, Manager St. Louis Transfer Railway.

January 2, 1889—"The Interlocking System of the St. Louis Bridge and Tunnel Railroad," N. W. Eayrs, C. E., St. Louis Bridge Company. "A New Power Drill for Quarries and Mines, with Notes on Mining in Colorado," J. A. Ockerson, Manager Silver Age M. & M. Company.

January 16—"Wrought Iron and Steel Eyebars," Carl Gayler, Bridge Engineer, City. "A Burr Truss," Prof. A. E. Phillips, Purdue University.

February 6—"Rainfall and River Discharge in the Mississippi Valley," Prof. F. E. Nipher, Washington University. "Adding Machines," N. W. Perkins, Jr., M. E.

February 20—"Elevated Railroads," Geo. H. Pegram, consulting engineer. "Tests of, and Specifications for, Cast Iron," Prof. J. B. Johnson, Washington University.

March 6—"Shortage on Coal in Car Lots," Thos. D. Miller, manager Fort Worth (Tex.) Gas Company. "Improving the Channel of the Mississippi," Winslow Allderdice, consulting engineer.

March 20—"Street Car Running Gear," B. F. Crow, superintendent Brownell & Wight Car Company. "Some Reminiscenses in connection with the Construction of the Union Pacific Railroad," C. H. Sharman, superintendent Illinois & St. Louis Railroad.

April 3—"The Boiler for Use in Coal Mines," Lewis Stockett, chief engineer Consolidated Coal Company. "Steam Plants for Electrical Service," Wm. H. Bryan, M. E.

April 17—"The Sanitary Condition of the Water Supply of New York City," Prof. Charles C. Brown, Union College, Engineer New York State Board of Health. "Easement Curves, Missouri Pacific Railway," Willard Beahan, engineering department, Missouri Pacific Railway.

May 1—"Some New Theories and Experiments on Boiler and Factory Chimneys," Prof. H. B. Gale, Washington University. "Experiments on Settling Water," Jas. A. Seddon, St. Louis Water-Works Extension.

May 15—"The Trussing of the Fagin Building against Wind Pressure," Prof. J. B. Johnson. "Fire-proof Flooring," P. M. Bruner, contractor.

June 5—"The Olive Street Cable Line," W. Bartlett, engineer. "Compound Engines," E. E. Furney, Missouri River Commission.

The following applications for membership were announced and referred to the Executive Committee:

Grant Beebe, indorsed by W. H. Bryan and F. H. Pond.

Wm. S. Lowe, indorsed by H. P. Taussig and N. W. Eayrs.

Wm. J McNulty, indorsed by J. A. Laird and A. W. Zeller.

R. L. Van Sant, indorsed by M. L. Holman and George Burnet.

A. T. Woods, indorsed by F. H. Pond and C. M. Woodward.

H. D. Wood, indorsed by F. H. Pond and W. H. Bryan.

After this came the toasts as follows:

"The Engineers' Club of St. Louis," responded to by T. A. Meysenburg.

"The Engineering Profession," responded to by Robt. Moore.

"City of St. Louis," responded to by E. D. Meier.

"The Engineer of the Past," responded to by E. C. Jewett.

"The Engineer of the Future," responded to by R. E. McMath.

Prof. Engler called the Club's attention to a movement in favor of a monument to Capt. Eads, and suggested that the Club take the lead in the matter.

[*Adjourned.*] W. H. BRYAN, Secretary.

NOVEMBER 21, 1888—296TH MEETING.—Club met at Washington University. at 8:10 P. M., President Holman in the chair; thirty-one Members and two visitors present. The minutes of the 294th and 295th meetings were read and approved, The Executive Committee reported the doings of its six meetings held since the Club adjourned last spring.

On motion of Mr. Russell the recommendation of the Executive Committee that an allowance of $100 be made the Secretary for his year's services, was approved by the Club.

The Executive Committee having approved applications for membership from

the following parties, they were balloted for and elected: Grant Beebe, draughtsman, Pond Engineering Company; Edmund Hall, assistant engineer, M. & O. R. R.; Wm. S. Love, draughtsman, Union Depot Company: Wm. J. McNulty, assistant engineer, St. L., I. M. & S. Ry.; R. L. Van Sant, assistant engineer, St. L. & S. F. R. R.; Arthur T. Woods, professor of mechanical engineering, University of Illinois.

Applications for membership were announced from Wm. F. Schaefer and Louis Simonds, both endorsed by S. B. Russell and Max G. Schinke.

Mr. R. E. McMath, of the Committee on National Public Works, reported a deficit of about $35, and by permission circulated a subscription paper among the Members present.

Mr. Robert Moore, Chairman of the Committee on Relations with Mercantile Library, reported that a meeting room could be had in the new building, but on what terms he was not yet prepared to state.

After some announcements by the Secretary, the paper of the evening, "Smoke Prevention," was read by Robert Moore. The author's treatment of the subject was very thorough. He showed that no saving need be expected, but that experiments showed a loss of 40 per cent. in boiler capacity when making no smoke. Most smokeless fuels cost too much, as compared with ordinary coal, to come into general use. In the author's opinion, the fuel promising the best results at reasonable cost was petroleum, already coming into extensive use. The increased cost of insurance and the odor, however, were disadvantages. Good results might be secured from that class of smoke preventers which introduced air above the grates by means of steam jets, providing no injury resulted to the boilers.

In the discussion Mr. Bryan called attention to the fact that petroleum burners were being placed under boilers in this city, and that it was expected that the increased cost would be justified by other advantages. He also mentioned furnaces at the Mississippi Glass Company fed by gas producers, where very high evaporative efficiency was reported. The general opinion of the Club was that little could be expected in this direction.

Col. Meier gave some experience which accorded well with the conclusions of Mr. Moore.

Mr. Wheeler stated that claims had been made that the soot particles were not only unobjectionable, but even remedial, from a sanitary point of view.

Mr. Bartlett gave the experience of the Olive street cable line with jets of steam and air. They were successful unless the boilers were injured.

Replying to Mr. Russell, Mr. Moore stated that the comparative costs of fuel given in his paper were based on actual values.

Mr. Holman stated that serious injury to boilers had resulted from the use of steam and air jets, and he had therefore refused to allow such devices to be applied to the water-works boilers, which are internally fired. A proposition had been received looking to the use of petroleum, an evaporation of 14 pounds of water per pound of oil being promised. The increased cost of this fuel over coal would be small.

I. A. Smith stated that while in charge of public buildings at Cincinnati a smoke ordinance was passed and he had used steam and air jets. These had since been removed, and after six years no reduction of smoke in that city was apparent.

Professor Gale was of the opinion that where steam plants of sufficient magnitude were used, gas producers would be found advantageous. There was, however, a lack of reliable data on this subject.

Some further general discussion followed.

On motion of Mr. Russell, the Executive Committee were authorized to employ a stenographer to report the discussions of papers at our meetings.

[*Adjourned.*] W. H. Bryan, Secretary.

WESTERN SOCIETY OF ENGINEERS.

NOVEMBER 14, 1888:—The 252d meeting was held, Vice-President Jno. W. Weston in the chair.

The minutes of last meeting were read and approved.

Mr. Lewis Passmore Pennypacker, proposed at last meeting, was elected a Member.

The resignations of Mr. A. M. Kinsman, Rockford, Ill., and Mr. J. T. Dodge, Duluth, Minn., were accepted.

The following financial exhibit is compiled from report of Secretary and Treasurer: Cash reported at last meeting, $107.82; receipts since last meeting, $35.95; bills paid, $82.50; cash on hand, $61.27; new bills reported, $56.00.

The Secretary read a letter from Prof. Allan D. Conover, University of Wisconsin, stating that a comprehensive system of tests of all the cements used in this country had been undertaken, and requesting information as to makers of cements and experience of Members. After brief discussion, the Secretary was directed to communicate with Professor Conover.

Mr. Liljencrantz, from Committee on Employment, reported that the matter had not been disposed of, and it was made a special order for next meeting.

Mr. Strobel, from Committee on Bridges, made an extended progress report and the question of legislation was discussed for the views of Members. The correspondence with other societies showed a wide and active interest. The Committee would report formally with the draft of a bill at a future meeting.

As legislation of kindred interest to engineers, the Secretary presented the desirability of expanding the duties of the State Board of Health so as to require its approval of all plans for water-works and sewerage. From a conversation with one of the Members of the Board, it was inferred that if the engineers of the State would unite in pushing the matter they would have the co-operation of the Board. No action was taken upon the suggestion.

The Secretary announced farther discussion upon Mr. Wisner's paper by Mr. B. Williams and Mr. T. T. Johnston and a compilation of data by himself, and that when the matter was all received and arranged it would be forwarded for publication.

An interesting paper, entitled "The Necessity of a Definite and Determinate System of Weights and Measures," by Mr. Chas. C. Breed, was presented by the Secretary and after brief discussion ordered printed.

Mr. Weston gave an interesting account of a mammoth electric light plant now under construction in the city of London. A general discussion in regard to the application of any motor to direct propulsion on street railways then ensued. There was some doubt of securing adequate adhesion under all the conditions of track obtaining in crowded cities.

A Committee was then appointed to present at the next regular meeting a program for the Annual Meeting, and to report upon nominations of officers and rules for their election.

Committee: Benezette Williams, S. G. Artingstall, A. W. Wright.

[*Adjourned.*] L. E. COOLEY, Secretary.

ENGINEERS' CLUB OF KANSAS CITY.

NOVEMBER 5, 1888:—A regular meeting was held at 8 P. M. in Club room, President W. B. Knight in the Chair. There were present 10 Members and 9 visitors.

Minutes of the previous meeting of the Executive Committee were read and approved.

W. H. Breithaupt read for the Committee on Highway Reform the draft of a

law prepared to be presented as a memorial to the State Legislature. Many of the local societies had given the subject favorable attention, and it was expected that a final report would be submitted in one or two months.

The Secretary read a letter from Mr. Benezette Williams, with reference to prolonging the contract with the *Railroad Gazette* for publishing the JOURNAL, and announced the following contributions to the library :

Proceedings Engineers' Society of Western Pennsylvania, Engineers' Club of Philadelphia, American Society of Civil Engineers, and a complete file of *The Mechanic*. Also, from Mr. H. J. Tullock, two handsome bridge photographs.

A paper on "Electric Railways" was read by Mr. J. F. Wynne and discussed by those present.

[*Adjourned.*] KENNETH ALLEN.

NOVEMBER 19, 1888:—An adjourned meeting was held in the club-room at 8 o'clock P. M., President W. B. Knight in the chair. There were present 12 Members and 9 visitors.

The Secretary being absent, the minutes of the two previous regular meetings and those of a meeting of the Executive Committee were read by Mr. Breithaupt and approved.

Dr. Wellington Adams gave an address on "The Present Status of the Electric Railway Problem," being in part a discussion of the paper read by Mr. Wynne at the last meeting. It was discussed by Messrs. Knight, Wynne and Lawless, the latter giving a review of a recent tour of inspection of the electric railways of Allegheny, Binghamton, Richmond and Harrisburg.

KENNETH ALLEN, Secretary.

MONTANA SOCIETY OF CIVIL ENGINEERS.

NOVEMBER 24, 1888:—An adjourned meeting was held at 8 P. M., at the office of Mr. E. H. Beckler, Chief Engineer Montana Central Ry., Mr. Beckler, 2d Vice-President, in the chair. These present were Messrs. Haven, Beckler, Foss, Kelly, Wade, Wheeler, Keerl and two visitors.

Mr. F. J. Smith was unanimously elected a Member of the society.

The Committee, consisting of Messrs. Haven, Foss and Beckler, appointed at the regular meeting of 20th ult., to consider and report upon an overhead crossing of the motor line at Main street and Sixth avenue, city of Helena, submitted their report. They recommend an elevated track for the motor line along Sixth avenue, leaving the grade of the street at a point near Close street, and crossing Main and Jackson streets at elevations giving sufficient head room, thence coming to grade at a point east of Jackson street. The details of the location and construction were discussed at length—the principal point being as to whether the elevated road should be placed over the sidewalk or the centre of the street. The report was received and the Committee discharged, with a vote of thanks for the careful attention they had given to the subject.

It was moved and carried that the consideration of the final adoption of the report of the Committee upon an overhead crossing of the motor line at Main street and Sixth avenue, Helena, be deferred until the next regular meeting, and that the Secretary be instructed to inform members that the subject will then be brought up for discussion.

A communication was read from Allan D. Cowan, Professor of Civil Engineering in the University of Wisconsin, requesting information upon the brands of cement manufactured and used in this section of the country. Members are requested to notify the Secretary if they know of any brands of cement being man-

ufactured in this section of country; also, what brands they know of being used, with name and address of manufacturer.

The question of arranging a programme for the annual meeting of the Society, to be held in January, was deferred until the next regular meeting.

Meeting adjourned, to meet December 15th next, at same hour and place.

J. S. KEERL, Secretary.

INDEX DEPARTMENT.

ANNUAL SUMMARY.

It is proposed to furnish, in this department, as complete an Index as may be of current engineering literature of a fragmentary character. A short note will be appended to each title, intended to give sufficient information to enable the reader to decide whether or not it is worth his while to obtain or consult the paper itself. The Index will be mostly limited to society and magazine articles, and special engineering reports of general interest and value. It is printed in the monthly issues of the JOURNAL, *on but one side of the paper, so that the titles may be cut out and pasted on cards or in a book, and is here collected with additional titles and many cross-references.*

All readers of the JOURNAL *are requested to aid in making the Index as complete as possible. All notices for this department, and all matter to be here indexed should be sent to* J. B. JOHNSON, *Manager Index Department, Washington University, St. Louis, Mo.*

Address. *Annual, to the Engineers' Club of Philadelphia.* By T. M. Cleemann, retiring President. Gives a comparion of the growth of engineering societies and a brief review of the work Philadelphia and Pennsylvania have accomplished. *Proc. Engrs. Club, Philadelphia*, Vol. VI., pp. 225–234 (Feb., 1888).

—— *of Retiring President, Engineers' Club of St. Louis.* By Wm. B. Potter. Gives brief history of the club and discusses its work and relations with other societies. *Jour. Asso. Engin. Soc.*, Jan., 1888, pp. 22–28.

——, *President's, Society of Engineers.* By Henry Robinson. Reviews engineering progress during the year. *Trans. Soc. Engrs.*, 1888, pp. 1–26.

——, *President's, Illinois Society of Engineers and Surveyors.* By I. O. Baker. Points out desirable changes in engineering practice of building roads, bridges, etc. *Rep. Ill. Soc. Engrs. and Surveyors*, 1888, pp. 14–27.

—— *to the Institution of Civil Engineers.* Gives the address of Geo. B. Brace on assuming the President's chair. A general review of engineering. *Engineer*, Nov. 11, 1887.

—— *to the Mechanical Science Section of the British Association, Bath*, 1888. By W. H. Preece, President of the section. Reviews the developments of the practical applications of electricity. *Engineer*, Sept. 7, 1888; *T. J. and Elec. Rev.*, Sept. 7, 1888; *Jour. Soc. Arts*, Sept. 14, 1888; *Sci. Am. Supple.*, Sept. 29, 1888.

Aluminum *Alloys by the Heroult Process.* Describes the method of producing aluminum alloys; also gives a table showing tensile strength and elongation obtained from a series of tests made at Zurich. *Engr. News*, Sept. 8, 1888.

——. *Influence upon Cast-Iron.* By W. J. Keep, Prof. C. F. Maybery and L. D. Voice, before the American Association for the Advancement of Science. A valuable paper, giving details of experiments made to determine the effects of aluminum on cast-iron. Good results were obtained by its use. *Sci. Am. Supple.*, Sept. 8, 1888.

——. *Recent Development of the Cowles Process.* By R. E. Crompton, before the Bath meeting of the British Association. Gives a description of the new plant for the production of aluminum at Milton, Eng. *T. J. and Elec. Review*, Sept. 14, 1888.

Alloys, *Copper-Tin.* A preliminary experimental research upon the mechanical properties of small castings of the alloys of copper and tin. Transverse, tension, torsion and compression tests in detail, with 81 plates and diagrams. By R. H. Thurston, Chairman. *Report Board of Testing*, etc., 1881, Vol. I., pp. 271–451.

Anemometers. *Experimental Investigations and Description of the Hagemann Anemometer.* By G. A. Hagemann. Translated by G. E. Curtis from the "Annuaire Météorologique" of the Danish Meteorological Institute, Copenhagen, 1877. *Journal of the Franklin Institute,* Sept., 1887, Vol. CXXIV., No. 741.

Angle Prisms. Discusses the construction and uses of angle prisms. *Eng. News,* May 12, 1888.

Aqueduct, *Croton, Method of Detecting Bad Work.* Gives a brief description of the methods employed to detect and repair the bad work on the Croton Aqueduct. *Engr. News,* Oct. 13, 1888.

——, *Croton, Tunnel Excavation.* A contractor's side of the tunnel excavation question. *Engr. News,* Oct. 20, 1888.

——, *Zempoala, Mexico.* Gives an illustrated description of Zempoala aqueduct, supplying the city of Otumba, which was built during 1553-7. *Engr. News,* July 7, 1888.

Arch, *Construction of a Skew.* By M. P. Paret. Gives a history of interesting points on the construction of a skew arch on the Cincinnati & Richmond R. R., near Red Bank, O. *Engineering News,* Oct. 20 *et seq.,* 1888.

——, *Stone, over South Street, Boston & Providence R. R.* Gives description, with plan, elevation and sections, of the stone arch of 40 feet span to replace the Bussey bridge. *R. R. Gaz.,* Dec. 30, 1887.

Arches. An abstract of a paper before the Engineering Section of Bristol Naturalist Society by Mr. C. Richardson, Engineer to Severn Tunnel. *Engineering,* Jan. 13, 1888. *Sci. Am. Supple.,* March 3, 1888.

——, *Arched Ribs and Voussoir.* By Mr. Martin, before a students' meeting of the Institution of Civil Engineers. Gives a mathematical discussion of arched ribs and voussoir arches. *Proc. Inst. C. E.,* Vol XCIII., pp. 462-477.

—— of long span and small rise, constructed with a joint at crown and springings of a hinge-like form, by insertion of lead plates in the middle third of these joints. Four such bridges described, erected 1885-87. Very good. *Zeitschrift fur Bauwesen,* 1888, p. 235.

——, *Stone.* Discusses the problem of the stone arch as designed from the catenary curve. *Eng. News,* Nov. 19, 1887; *Mech. World,* Dec. 17, 1887.

Asbestos. By S. A. Rogers, before the Chemists' Assistants' Association. Reviews the history, occurrence and properties of asbestos. *Sci. Am. Supple.,* June 16, 1888.

Axle, *Standard for* 60,000-*lb. car.* A paper by A. Forsyth, presented to January meeting of Western Railway Club by the committee on axles as their report. It discusses dimensions and loads, factor of safety and friction. *Mast. Mechanic,* Feb., 1888.

——, *Standard for* 60,000-*lb. car.* By H. C. Meade, before January meeting Western Railroad Club. Gives comparison between the Johann and M. C. B. axles. *R. R. Gazette,* Feb. 10, 1888; *Mast. Mechanic,* Feb., 1888.

Axles, *Effects of Temperature on the Strength of.* By Thos. Andrews. Abstract of a paper before the Institution of Civil Engineers, giving valuable experimental research on the effect of varying temperatures on the resistance to impact of railway axles. *Engr. News,* Feb. 18, 1888.

——, *Steel Car.* A paper by John Coffin before the Philadelphia meeting of the American Society of Mechanical Engineers. Discusses the treatment of the axle after it is forged. *Trans. Amer. Soc. Mech. Engrs.,* Vol. IX. (1888), pp. 135-160; abstracted *R. R. Gazette,* Dec. 23, 1887.

——. See Car Axles and Car Wheels.

Batteries, *Primary, for Illuminating Purposes.* By Perry F. Nursey, before the Society of Engineers. Treats briefly the principles of the primary battery, outlines its history and then describes in chronological order the various batteries brought out. *Trans. Soc. Engrs.,* 1888, pp. 185-223.

Belting. *Origin and Progress of Leather Belting.* With description of leath link belting. Paper read before the National Electric Light Association, Pittsburgh by Charles A. Schieren. *Electrical World,* March 3, 1888; *Electrical Engineer,* March, 1888; *Age of Steel,* March 10 and 17, 1888.

Blowers, *Experiments and Experience with.* By H. I. Snell, before the Philadelphia meeting of the American Society of Mechanical Engineers. *Trans. Amer.*

trains. The main feature of improvement suggested is that the power of th brake should increase with the *load* in the car. By A. K. Mansfield. *The Railroad and Engineering Journal*, January, 1888.

Brake Tests, *Westinghouse.* Gives details of the test made at Weehawken with a train of 50 empty freight cars. *Eng. News*, Nov. 25 1887; *R. R. Gaz.*, Nov. 25, 1887; *Nat. Car and Loco. Builder* for December, 1887. Gives table of the tests at various places.

Brakes, *Classification of Continuous Railroad.* By A. W. Metcalfe, before the Students Institution of Civil Engineers. Gives a classification of railroad brakes based upon the general principles of action. *Proc. Inst. C. E.*, Vol. XCII., pp. 315-335.

——, *Freight Train.* Gives a paper by Mr. Lauder, and the discussion that followed it at the December meeting of the New England R. R. Club. *R. R. Gaz.*, Dec. 23, 1887, also *Mast. Mechanic*, January, 1888.

——, *Freight.* A paper by H. H. Westinghouse before the New York Railroad Club. Describes the construction, operation and maintenance of brakes. With discussion by the Club. *Mast. Mechanic*, February, 1888; *R. R. Gazette*, Jan. 27, 1888.

——, *Buffer.* A brief article explaining, with formulæ, the nature and action of buffer brakes. *Master Mechanic*, April, 1888.

Bridge, *Arthur Kill.* Gives a brief description, with plan and details of the drawbridge recently constructed between Staten Island and New Jersey. Total length of draw, 496½ feet ; clear water-way, 206 + 204 feet. *R. R, Gazette*, June 22, 1888.

——, *Brunswick, Eng.* Gives two-paged plate showing elevation and details of a hinged-arch foot bridge, spans 79 feet, over the River Oker at Brunswick, England. *Engineering*, Aug. 17, 1888.

——, *Ben Rhydding, Eng.* Gives brief description with two-page plate of detailed drawings, of two lattice arches, with suspended roadway, over the River Wharfe near Ben Rhydding, Yorkshire. *Engineer*, May 25, 1888.

——, *Big Warrior River.* Gives a brief description of a 300-foot through span over the Big Warrior River, near Cordova, Ala., with full detailed drawings. *R. R. Gazette*, June 29, 1888; *Sci. Am. Sup.*, July 21, 1888.

——, *Brooklyn.* Gives report of the Committee on Terminal Facilities, and the adopted plans for the terminals. *Engin. News*, April 21, *et seq.*, 1888; *R. R. Gazette*, April 27, 1888; *Engin. and Build. Rec.*, April 21, 1888.

——, *Brooklyn, Enlarging the Capacity of the.* Gives the report of the Beard of Experts on the plans for enlarging the capacity of the Brooklyn bridge; also the report submitted to the Board by Mr. A. M. Wellington. *Engr. News*, March 17, 1888.

——. See Foundations.

——, *Cairo.* By S. F. Balcom. Gives brief description of the Cairo bridge, and describes some of the details of construction and progress of the work. *Rept. Ill. Soc. Engrs. & Surveyors*, 1888, p. 75-84; and *Railroad Gazette*, June 1, 1888.

——, *Cantilever, Lachine.* Gives description with a two-page plate, with details of the bridge across the St. Lawrence River. *Engineering*, April 13, 1888.

——, *Cantilever, Sukkar.* By Wm. Parsey. Gives a description of staging and temporary erection of the Sukkar cantilever bridge at the bridge works. The bridge has a span of 820 feet, with a centre span of 200 feet. A two-page plate gives details of staging, etc. *Engineering*, March 2, 1888.

——, *Chenab, India.* Gives two pages of detailed drawing and abstracts from the specifications of the Chenab bridge, India state railroads. It is composed of 17 spans, of 206 feet each, of riveted triangular girder. *Engineer*, Sept. 14, 1888.

——, *Draw.* See Draw-bridge.

——, *Forth.* By F. E. Cooper, before the Iron and Steel Institute. Gives a general description of the methods employed in the erection of the various portions of the main span. Abstracts in *Engineer*, Aug. 24, 1884; *Engr. News.*, Sept. 22, 1888; *Sci. Am. Supple.*, Oct. 13, 1888.

——, *Forth, Erection of.* By A. S. Biggart. A paper before the British Association, treating of the problems that occurred during the erection of the Forth bridge and methods of overcoming them. Illustrated. *Engineer*, Nov. 25, 1887 ; *Sci. Am. Sup.*, Dec. 31, 1887.

——, *Forth, Erection of Superstructure.* By A. S. Biggart, before the Scotland In

Niagara suspension bridge with iron towers. *Trans. Am. Soc. C. E.*, Vol. XVII. (Oct. 1887), pp. 204-212, *Engineer*, Dec. 9, 1887 ; *Engineering*, Dec. 9, 1887 ; abstracted *Proc. Inst. C. E.*, Vol. XCIII., pp. 510-512.

Bridge, *Paderno, Italy.* Gives brief description, with elevation and cross section, of a bridge to be built over the river Adda, at Paderno, Italy. Length of main arch, 492 ft.; rise, 123 ft.; lattice truss spans, 109 ft.; total length, 997 ft. *R. R. Gazette*, Sept. 14, 1888.

——, *Petaluma Draw.* Gives brief description, with general view and plan and elevation, of the central pier of the Petaluma draw-bridge on the San Francisco & North Pacific Railroad. *Engr. News*, Oct. 13, 1888.

——, *Plate Girder.* See Girder.

——, *Pony Lattice, W. S. R. R.* Gives plan, elevation and cross-section, with dimensions of a pony lattice bridge truss built at Normanskill, N. Y., on the West Shore Railroad. Span, 86 ft.; clear width, 14 ft.; height, 10 ft., and weight, 50 tons. *R. R. Gazette*, Sept. 21, 1888.

——, *Poughkeepsie.* A series of articles on the erection of the Poughkeepsie bridge. *Engin. and Build. Rec.*, May 5, *et seq.*, 1888.

——, *Poughkeepsie.* By Thomas C. Clark. The Second Sibley College lecture describing the erection of bridge over the Hudson at Poughkeepsie. *Sci. Am. Suppl.*, May 19, 1888.

——, *Proposed North River.* By G. Lindenthal. Gives brief description of the proposed bridge, also gives a full page plate comparing the bridge with four of the greatest bridges in the world. *Engr. News*, Jan. 14, 1888, and *Engr. and Build. Rec.*, Jan. 14, 1888.

——, *North River, Proposed.* By Gustav Lindenthal, before the American Society of Civil Engineers. Gives very full details of the proposed bridge over Hudson River, at New York. Proposed dimensions are: River span, 2,850 feet; two shore spans, 1,800 feet; width, 68 feet, with six railroad tracks; height above water, 145 feet. Abstracted in *Eng. News*, Jan. 28, *et seq.*, 1888.

——, *Ravine Lowestaft.* Description, with elevation and details, of a wrought-iron arched bridge. The arch ribs are made of ¼-inch web plate and angle iron. *Engineer*, Sept. 2, 1887.

——, *Red River, Concrete Piers.* By C. D. Purdon. Gives details of the construction of concrete piers for the St. Louis & San Francisco R. R. bridge over Red River, Texas. *Engr. News*, June 2, 1888.

——, *River Ouse, Bedford, Eng.* Gives plan, elevation and cross-section of a footbridge of 100 ft. span, practically without abutment. *Sci. Am. Supple.*, Sept. 8, 1888.

——, *Staging, Sukkur, India.* A brief description, with large colored plate, of the staging for the main pillars and guys of the 820-foot cantilever span of the Sukkur bridge. *Indian Engineering*, Nov. 5, 1887.

——, *St. Louis, Reconstruction of the Floor of.* By N. W. Eayrs. Gives details, with drawings, of the plan adopted in the reconstruction of the railroad floor of the St. Louis bridge. *R. R. Gazette*, Aug. 31, 1888.

——, *Suspension, Vishwamitri River.* Short description and abstract from specifications of a chain suspension bridge of 190 feet span, with two large plates showing elevation and details. *Indian Engineering*, Dec. 10, 1887.

——, *Sin Ho, China.* Brief description, with elevations, cross section and half plans showing bracing of the Sin Ho bridge. *Engineer*, Dec. 9, 1887.

——, *Three-Hinged Iron Arch.* By J. H. Cunningham. Gives description, with details, of a three-hinged, wrought.iron arch constructed at Claremont, Ia. *Engineering*, Aug. 12, 1887.

——, *Torkham, India.* Describes the method employed to launch three short spans of riveted girder of Torkham bridge. Illustrated. *Indian Engineering*, Oct. 1, 1887; *Eng. News*, Nov. 19, 1887; *Engineering*, Jan. 13, 1888.

——, *Tay.* By Peter Barlow, before the Institution of Civil Engineers. Gives principal dimensions and general data of the Tay viaduct. *Sci. Am. Suppl.*, June 16, 1888.

——, ——. By Wm. Ingliss, before the Institution of Civil Engineers. Gives details of the construction and difficulties overcome of the Tay viaduct. *Sci. Am Suppl.*, June 16, 1888; *R. R. Gazette*, June 29, 1888.

——, *Wells Street, Chicago, Removal of the.* Gives details of the moving of the

Bridge Inspection. Gives the order to bridge inspectors in use on the Buffalo, Rochester & Pittsburgh Railroad. *Engin. News*, May 12, 1888.

——, *Inspection and Maintenance of.* A discussion at the annual convention of the American Society of Civil Engineers on the inspection and maintenance of railway structures. The discussion, by many prominent engineers, covers 50 pages in the *Trans. Am. Soc. C. E.*, Vol. XVII., December, 1887.

——, *Selection and Maintenance of.* By D. W. Mead. Gives hints relating to the selection and maintenance of bridges for cities. *Rep. Ill. Soc. Engrs. and Surveyors*, 1888, pp. 65–68.

—— *Pins and Eye Bars, Proportion of.* By C. F. Stowell. Discusses the present state of pin calculation and gives formula for computing the stress in the side of the head of eye-bars. *Engr. News*, March 31, 1888.

Bridge Strains, *Slide Moment Diagram for Computing.* By J. E. Greiner, before the Engineers' Society of Western Pennsylvania. Gives a description of a slide moment diagram, which has been in use in the Baltimore & Ohio office for three years, and is considered the best method of finding shears and moments in bridges. Abstracted in *Engin. News*, April 14, 1888.

Bridges, *Stresses in Lattice, New Method of Obtaining.* By Wm. Robertson. Gives a new geographical method of computing the strains in lattice bridges. *Engineer*, Dec. 30, 1887. *Sci. Am. Supple.*, March 24, 1888.

——. *Graphical Evolution of Stress in Lattice Girders.* By Wm. Robertson. Gives a comparison between the values of the stresses in the flanges of various forms of latticing as determined by their numerical evolution and the ordinate to the parabolic curves of moments, and deduces rules for graphical solution. *Engineer*, March 16, 1888.

Bridge Work *and Inspectors.* By S. T. Wagner, before the Annual Convention of the American Society of Civil Engineers. Discusses the characteristics and work of bridge inspectors and makes suggestions for their work. Discussion. *Trans. Am. Soc. C. E.*, Vol. XVII., December, 1887, pp. 319–329.

Building Materials *and their use in Fire-Proof Construction.* By S. E. Loring. An illustrated series describing the best and latest practice in the construction of fire-proof buildings. *Building*, Dec. 17, 1887, *et seq.*

Buildings, *Steel Plate.* Detailed plans and descriptions of a method of constructing buildings with embossed galvanized steel plates. *Sci. Am. Supple.*, Nov. 5, 1887.

Cables, *Chain.* A full discussion of the determination of the character of iron best adapted for chain cables, the best form and proportions of links, with details of the testing of a large number of specimens. *Report U. S. Board on Testing*, Vol. I., 1881, pp. 1-238.

——, *Steel.* Abstracts from the specifications for the steel cables for Birmingham cable roads. *Engineer*, Aug. 12, 1887.

Cable Railroad, *East River Bridge.* By G. Leverich, before the American Society of Civil Engineers. Gives a very complete description of the road, plant and particulars of traffic and operation, details of wear, renewals and changes, with 28 plates showing details. Very valuable. *Trans. Am. Soc. of C. E.*, Vol. XVII. (March, 1888), pp. 67-102.

Cable Roads, *Birmingham, Eng.* Gives a brief description, with a two-page detailed drawing, of the Birmingham cable road. *Engineer*, June 22, 1888.

——, *Edinburgh.* Gives constructive details of the Edinburgh Northern Cable Tramway, with description. *Engineer*, Oct. 28, Nov. 4 and 11, 1887.

——, *Otto System.* Describes the installation prepared for the New Castle Exhibition, with illustrations showing details. *Engineering*, April 6, 1888.

Canal, *Manchester Ship.* A series of articles describing in detail the progress made and methods employed in the construction of the Manchester ship canal. *Engineering*, May 18, *et seq.*, 1888. Abstracted *Eng. News*, June 30, *et seq.*, 1888. *Engin. and Build. Rec.*, Sept. 29, *et seq.*, 1888.

——, *Manchester Ship.* Gives brief review of the above project, with particulars of the work to be done and methods of operation. *R. R. Gazette*, Sept. 14, 1888.

——, *Manchester Ship, Plant and Machinery.* By L. B. Wells, before the Bath meeting British Association. Gives a brief description of the principal machinery now in use on the Manchester Ship Canal. *Engineer*, Sept. 21, 1888.

——, *Nicaragua, Location of,* 1888. Gives maps showing results of the survey of the

sanitary, economical and political consequences. *Jour. Assoc. Engin. Soc.*, August, 1888, Vol. VII., pp. 313-329.

Canal Conference, *Society of Arts.* At a conference recently held under the auspices of the Society of Arts, fifteen papers on canals and inland navigation were presented. They cover the use, history, progress and present condition of canals, their influence on railroads, and a comparison of the costs of traffic on each. *Jour. Soc. Arts*, May 28, *et seq.*, 1888.

Canal Engineering. By L. F. Vernon-Harcourt, before the Society of Arts Canal Conference. Treats of the past, future aims and the prospects of canal engineering in the future. *Jour. Soc. Arts*, May 25, 1888.

Canal Lift, *Fontinettes, France.* Gives a discussion on canal lifts *vs.* locks, and a description, with view, of the hydraulic lift at Fontinettes, France. *R. R. Gazette*, Sept. 21, 1888; *Engr. & Mining Jour.*, Sept. 29, 1888.

Car, *Coal, 60,000 lbs. Capacity.* Gives drawings of a 60,000 lbs. capacity coal car for the Georgia Pacific Railroad. *Nat. Car and Loco. Builder*, June, 1888.

——, *Standard 50,000 lbs.* Gives detailed drawing and specification of a standard 50,000 lbs. box car, for the Minneapolis, Sault Ste. Marie & Atlantic Railroad. *Master Mechanic*, November, 1888.

——, *Standard 50,000-lb. Freight.* Gives brief description with drawings and bill of material, of the standard 50,000-lb freight car of the Lehigh Valley Railroad. *R. R. Gazette*, June 8, 1888.

——, *Standard 50,000-lb Gondola.* Gives detailed drawing, with abstract from specification for the standard 25-ton gondola car of the Newport News & Mississippi Valley Co. *R. R. Gazette*, April 6, 1888.

——, *Twin Hopper 60,000-lb. Gondola.* Gives description, with bill of lumber and detailed drawing, with dimensions, of a twin hopper bottom gondola car having a capacity of 60,000 lbs. recently constructed for the Lehigh Valley Railroad. *R. R. Gazette*, Sept. 14, 1888.

——, *50,000-lb. Box, C., B. & Q. R. R.* Gives plan, elevation and cross-section, with full dimensions, of the 50,000-lb. box-car inuse on the Chicago, Burlington & Quincy Railroad. *Master Mechanic*, October, 1888.

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NOTE.—For all Government publications and information concerning the same, send to J. H. Hickcox, 906 M street W, Washington, D. C.

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